[Red Rovers Return: Fold-Out Guide to 3 New Mars Missions]

POPULAR science

Space Shuttle: THE Next GENERATION

The Best Concepts & Designs

I Was Shot by the Army's PAIN BEAM

FORENSICS: Murder Scene Reconstruction

Driving with a CRASH-TEST HUMAN

MACH 6 GRYPHON LAUNCHER CONCEPT

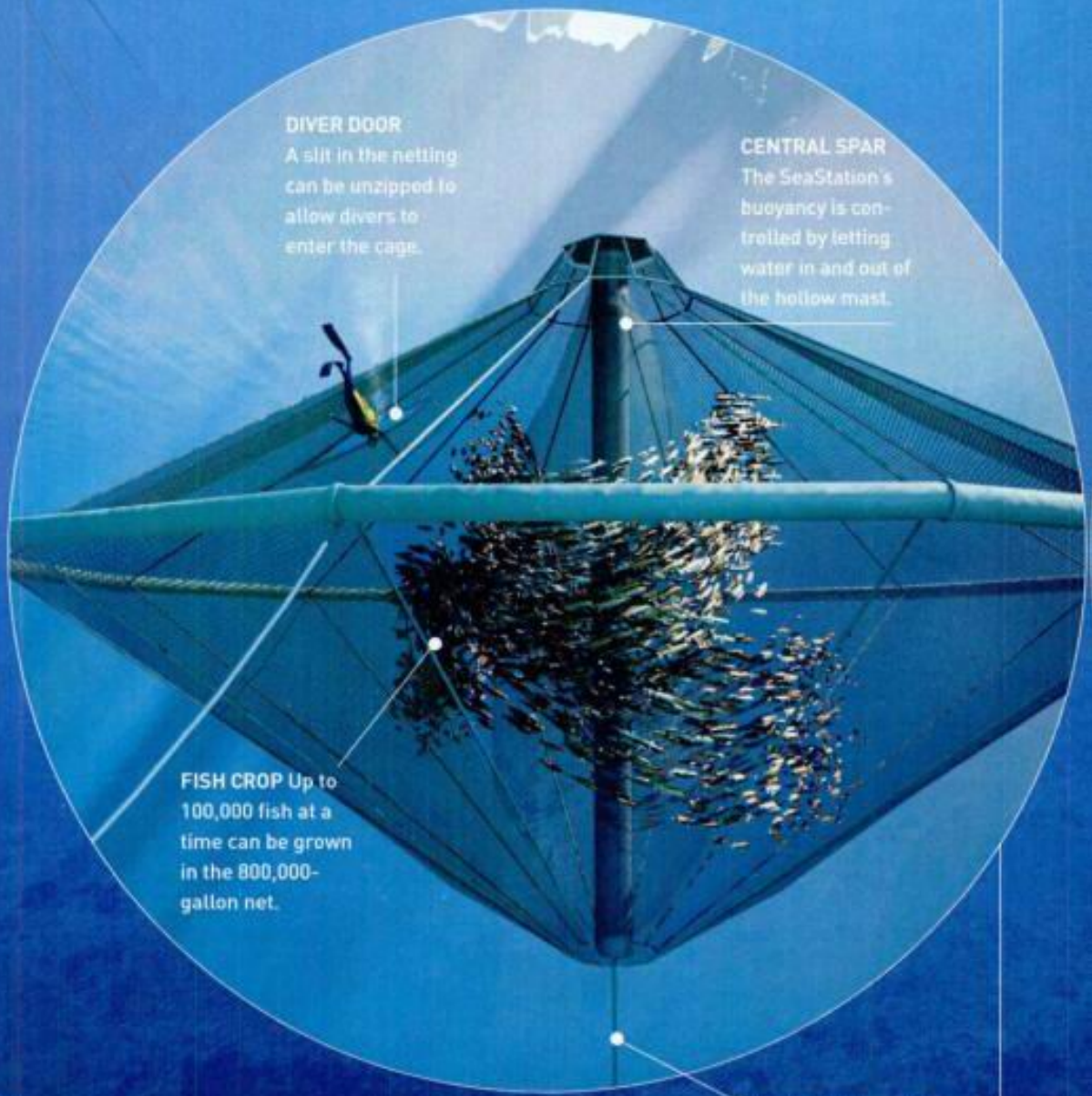
US $3.99 CAN $4.99
MAY 2003
popsci.com

THE SEASTATION

A farm in the form of a deep-sea fish tank

Designed to hover a full 40 feet below the surface of the ocean, the SeaStation cage is the world's first mass-produced offshore fish farm. The four-story central spar is flooded to sink the cage, which can remain submerged for months at a time. Young fish are deposited into the net (and later fed a slurry of fish meal) through hoses from boats at the surface. The cage is raised again when the fish are ready to be harvested.

SUPPLY BOAT Fish can be fed either by a visiting boat or by a barge moored at the surface.



DIVER DOOR A slit in the netting can be unzipped to allow divers to enter the cage.

CENTRAL SPAR The SeaStation's buoyancy is controlled by letting water in and out of the hollow mast.

FISH CROP Up to 100,000 fish at a time can be grown in the 800,000-gallon net.

ANCHORING SYSTEM The farm is tethered to the ocean floor with several separate lines.

BALLAST Hung from a line at the bottom of the net, a weighted disk increases stability.

Материал, защищенный авторским правом

ISS IN SURVIVAL MODE

200 TONS, 3 PEOPLE, 250 MILES UP, MOVING AT 17,000 MPH. THE SHUTTLE IS GROUNDED. WHAT'S A SPACE STATION TO DO?

Solar arrays and thermal radiators: To slow orbital decay, they might be folded to reduce drag from thin atmospheric gases.

Progress cargo ship: These and shuttles periodically boost station's orbit by firing rockets. Sans shuttle, there's a fuel shortage.

Thermal radiators

Zvezda

A

Solar arrays

Zarya

Main truss

Destiny

B

Node 3

Kibo laboratory (Japan)

Node 2

Columbus laboratory (Europe)

Current shuttle docking position: It's located at the end of Destiny.

Soyuz lifeboat: It is now the only way to get people to and off ISS. There's always one docked at the station.

Solar arrays

WHERE THE CREW LIVES

A Two crew members bunk in Russian-built Zvezda module.

B One crew member sleeps in U.S.-built Destiny lab, the ISS research center.

KEY: ISS NOW—AND PLANNED

- ■ SECTIONS INSTALLED AS OF APRIL 2003
- ■ WORK NEEDED TO GET ISS TO U.S. CORE COMPLETE STAGE
- ■ NASA'S LAUNCH COMMITMENTS AFTER CORE COMPLETE
- □ SECTIONS CANCELLED OR ON HOLD

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After Columbia, A New Game Plan

2003 was to be a key year for ISS construction, with seven shuttle missions getting the station to a first phase called U.S. Core Complete (see key on opposite page) by early 2004. Suddenly, on Feb. 1, NASA and its 15 partners faced some hard choices and challenges.

EVACUATE IMMEDIATELY?

No. A day after the disaster, NASA announced there was food until June, even without resupply. (An unmanned Progress freighter launched the next day, on schedule, and docked with ISS 2 days later.) A Soyuz lifeboat is always attached for emergencies.

KEEP A CARETAKER CREW

Construction has halted, and the crew will focus on maintenance, with spare parts in short supply. Three people crew ISS on six-month shifts called expeditions, with the next crew change planned for March. (At press time, it wasn't clear how long the current expedition would be extended.) Crew swapping will now be via Soyuz, not shuttle, and shuttle crews will need special training for that. Bigger problem: Russia is short of one-time-use-only Soyuz and Progress craft and needs 12 to 18 months to build more. Expect new orders.

BOOST THE ORBIT

Tiny amounts of atmospheric drag slow the station down, pulling it 500 feet closer to Earth every day. Without the shuttle's engines to help push it back up, the ISS must rely only on Russian Progress ships for periodic boosts. These freighters are less powerful than the shuttle. NASA says it's not a problem this year, but by 2004 it could be. Crew may "feather" the solar arrays to reduce drag, but that saps the power supply.

ACCELERATE DEVELOPMENT

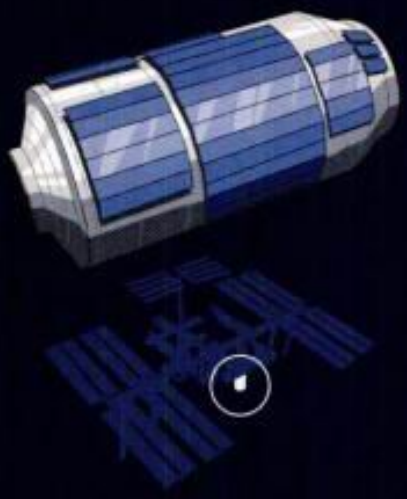
If the Columbia tragedy is to have any positive effect, it will be to speed the development of the Orbital Space Plane, bottom right, and other launch systems. NASA needs new ways to get freight and people safely into orbit at a lower cost than that of the shuttle.

Freighters and People Haulers

Here's the current roster of ISS supply and crew vessels planned by Europe, Japan and the U.S.

Automated Transfer Vehicle (ATV)

BACKER: European Space Agency
DATE: Late 2004, but ESA says could be rushed into service earlier
CAPACITY: 8.5 tons of cargo, including fuel, versus 2 tons on Russian Progress
PURPOSE: Unmanned craft built to take supplies to ISS



H-II Transfer Vehicle (HTV)

BACKER: National Space Development Agency of Japan
DATE: 2007-2008 (est.)
CAPACITY: 7.7 tons of cargo and experiments
PURPOSE: Unmanned craft for delivering supplies and experiments to station; it will also service the Japanese Kibo lab, previously scheduled to go to ISS in 2006. Without the shuttle, Kibo is grounded

Orbital Space Plane (OSP)

BACKER: NASA
DATE: 2010 (est.)
CAPACITY: 5 astronauts; limited cargo
PURPOSE: A crew transfer vehicle and station lifeboat. Often mistakenly mentioned as a shuttle replacement, the OSP would have to work in conjunction with a heavy cargo lifter before the shuttle could be retired

INFOGRAPHIC BY JASON LEE

Материал, защищенный авторским правом

STEP 5

Switch on the Sun Lamp

Cheaper, more efficient materials can send solar soaring

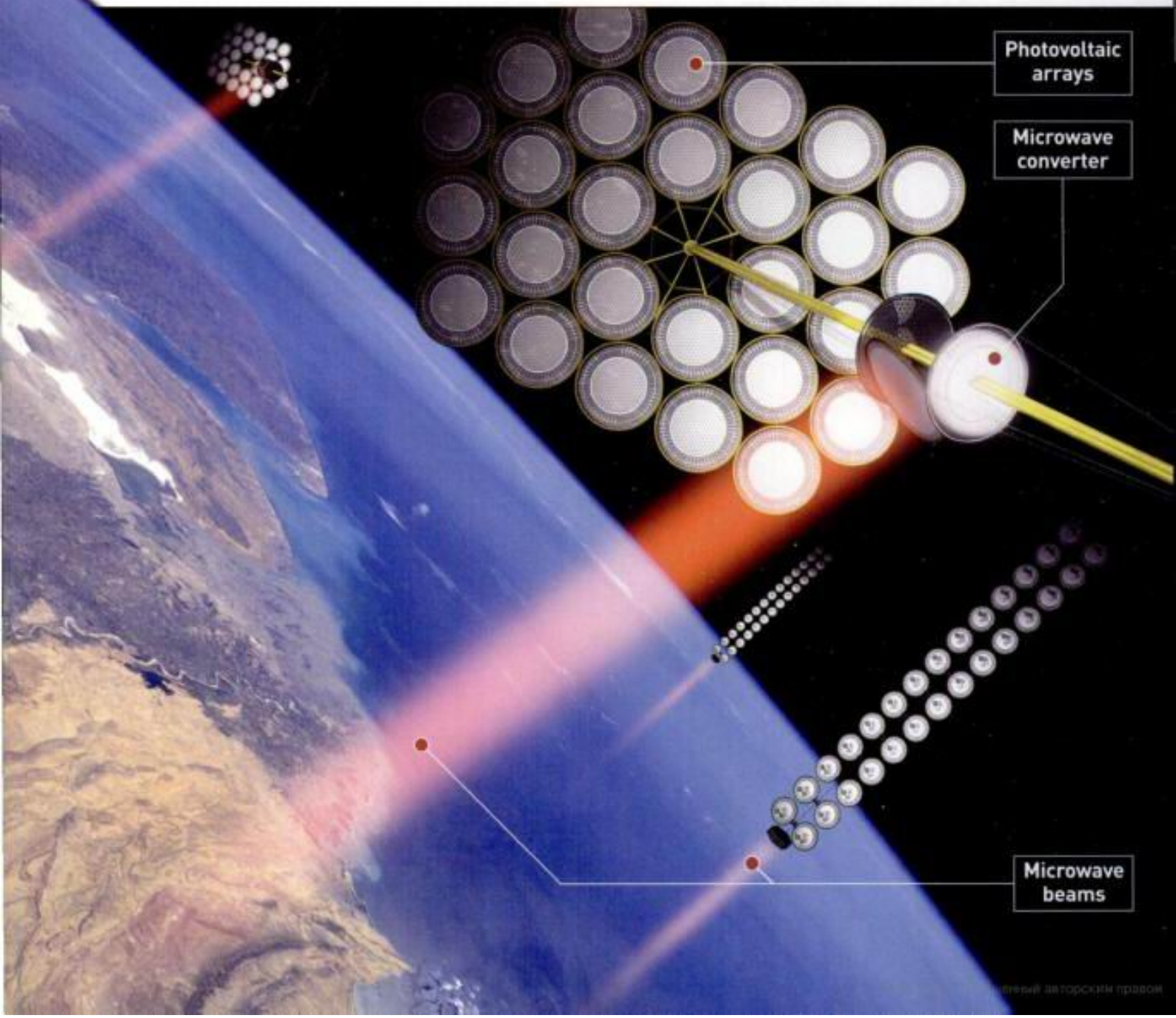
SOLAR POWER

POWER POTENTIAL 520 billion kWh
CO_2 DISPLACED 500 MMT
ELECTRICITY NEEDS MET 10%

EARLY NEXT YEAR, dozens of huge, concave mirrors will begin to sprout on a desert farm northeast of Los Angeles. Each 37-foot-diameter Stirling dish will electronically track the sun and reflect its rays onto a heat collector, where the concentrated sunlight will superheat hydrogen to 1,300°F, driving an electric generator by Stirling engine. Once the world's largest solar-energy farm is completed, some 20,000 dishes will stretch over 4,500 acres of the Mojave Desert, producing power for up to 278,000 homes.

Enough sunlight reaches the Earth every hour to meet the world's energy demand for an entire year. We have long known how to capture the sun's dispersed energy for space and water heating, but turning sunlight into volts is a trickier proposition.

Stirling solar dishes can convert about 30 percent of the sun's energy into electricity, making them today's most efficient solar-electric technology. (The Mojave farm will generate more electricity than all of the existing solar farms in the U.S. combined.) But most of us equate solar power with photovoltaic cells, the flat panels mounted on roofs and in backyards. These cells convert only 15 percent of the sun's energy into electricity, but their promise lies in their ability to produce power at points of consumption, relieving



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overstressed electric grids and turning any sunlit surface into an energy-collection device. Photovoltaic technology is already beginning to allow us to charge our cellphones and iPods through solar-collecting backpacks. In the not-so-distant future, we'll charge such devices through our shirts and jackets. Eventually, we may power up our hybrid cars through solar-collecting painted surfaces, and someday we may even fly cross-country on solar-powered airplanes.

That kind of potential will be realized by research focused on capturing more energy per square inch and by lowering the cost of essential materials. Scientists at Pennsylvania State University are creating solar cells out of titania nanotubes and natural dyes. At the University of New South Wales in Australia, researchers are trying to capture a broader range of energy within the solar spectrum by embedding nanoscale quantum dots in a matrix of silicon oxide. By varying the quantum dots' size, they hope to expand the solar cell's absorption spectrum—and achieve efficiencies of up to 50 percent. Meanwhile, developers of so-called thin-film technology are aiming to replace today's expensive silicon surfaces with layers of organic semiconducting materials only a few micrometers thick. These clear films could be added to rooftop shingles, sidings or even curtains, transforming them into devices that harvest energy and pay the electric bills.

Other energy entrepreneurs are thinking bigger. Much bigger. NASA scientists have long dreamed of harnessing the sun's energy in space and beaming it down to our homes by microwaves [below]. Yes, it's far-out, but dedicated microscale research may very well make it possible.

THE ORBITAL SOLAR STATION

Space-based sun collectors could eventually meet all our power needs

No, it won't happen by 2025. But vast arrays of solar panels lofted into space might someday beam microwave energy back to large antennas on Earth, where the waves would be converted into electricity. It's safer than it sounds—a wide beam means that birds and planes wouldn't be fried in flight. Geosynchronous orbit could keep the panels in the sun nearly 24/7. The biggest technical challenge: launching the device into orbit.

BOB SALES

STEP 6

Go H_2

The key: cleaner conversions

HYDROGEN POWER

POWER POTENTIAL Unknown
CO_2 DISPLACED Unknown
ENERGY NEEDS MET Unknown

THE POTENTIAL is huge, but the transition to the much-ballyhooed hydrogen economy won't be easy. Pure hydrogen isn't a naturally occurring fuel, and today the cheapest way to make it is from oil or natural gas, which does nothing to offset CO_2 emissions.

Still, hydrogen-powered fuel cells are already more than twice as efficient as internal combustion engines. In Iceland, renewable power sources make a hydrogen economy feasible. In the U.S., hydrogen may someday be produced with surplus wind power. Or researchers could even genetically engineer organisms to directly convert sunlight into hydrogen. Which just might deliver that sunny hydrogen-based future after all.

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LOOK OUT BELOW
The unmanned Switchblade may use Small Diameter Bombs, whose wings unfold upon deployment to increase their range.

THE SUPERSONIC SHAPE-SHIFTING BOMBER

With a shift of its wing, the Pentagon's next attack drone goes from long-range endurance flyer to Mach-speed assassin

FOR YEARS, the U.S. military has wanted a plane that could loiter just outside enemy territory for more than a dozen hours and, on command, hurtle toward a target faster than the speed of sound. And then level it. But aircraft that excel at subsonic flight are inefficient at Mach speeds, and vice versa. The answer is Switchblade, an unmanned, shape-changing plane concept under development by Northrop Grumman.

When completed (target date: 2020), it will cruise with its 200-foot-long wing perpendicular to its engines like a normal airplane. But just before the craft breaks the sound barrier, its single wing will swivel around 60 degrees (hence the name) so that one end points forward and the other back. This oblique configuration redistributes the shock waves that pile up in front of a plane at Mach speeds and cause drag. When the Switchblade

SWITCHBLADE

OBJECTIVE To function efficiently as both an endurance aircraft and as a supersonic airplane by changing its shape midflight
TIME FRAME Design by 2007; one-fifth-scale technology demonstration vehicle by 2010; ready for service as early as 2020
WINGSPAN 200 feet
RANGE 5,000 nautical miles
MAX. ALTITUDE 60,000 feet
MAX. SPEED Mach 2

JOHN MACNEILL

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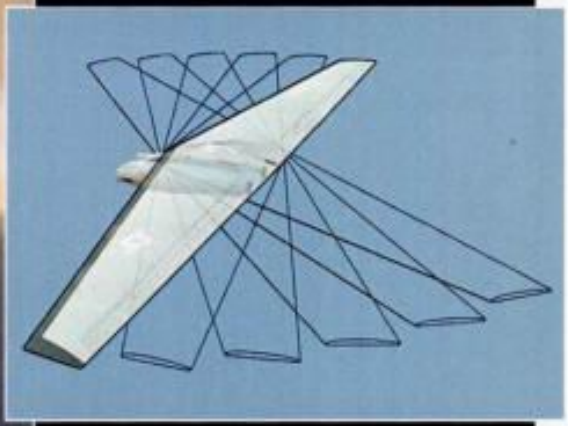
WINGING IT With its long, thin wing in a standard configuration, the Switchblade can maintain subsonic speeds for at least 15 hours as it waits for a mission.

SPEED BURST With its wing cocked forward, the Switchblade flies at Mach 2 toward a target up to 2,500 nautical miles away.



MAKING THE SWITCH As the plane approaches the sound barrier, its wing pivots into an oblique configuration to maximize aerodynamic efficiency at supersonic speeds.

returns to subsonic speeds, the wing will rotate back to perpendicular.

Smart plan. Now for the hard part: designing the thing. Darpa, the Pentagon's way-out research arm, has coughed up $10.3 million to Northrop Grumman to produce a detailed blueprint by November 2007. A flying test vehicle is due about four years later. The initial concept calls for a single wing with engines situated in a pod underneath, along with munitions and surveillance equipment. This setup will enable the wing to pivot while the engines remain pointed in the direction the craft is traveling.

This is not the first attempt at an oblique-wing aircraft. *SpaceShipOne* creator Burt Rutan designed a switch-wing plane with NASA in 1979. But the slanted wings made the craft hard to fly—when the pilot pulled the nose up, the plane would roll to one side.

The Switchblade, however, is a good candidate to be an unmanned aerial vehicle (UAV). The artificial intelligence used to control UAVs can handle the tricky flight dynamics, and a computer pilot doesn't need to eat, rest, or go to the bathroom—useful for those 15-plus-hour missions.

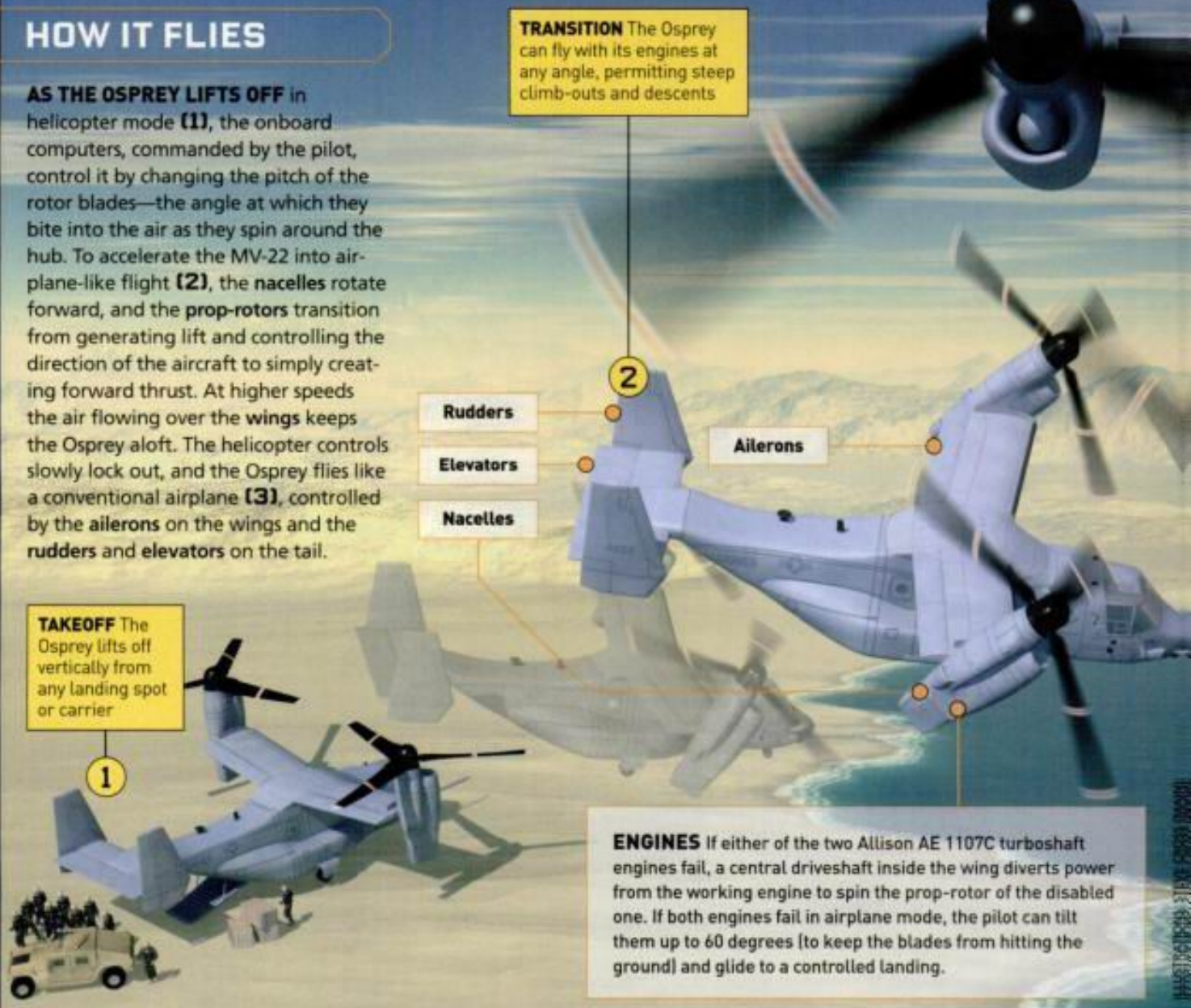
If all goes well, Darpa says, a 40-foot-wingspan demonstration model could be ready by 2010, and a full-size Switchblade should be all set for a brawl by 2020.—NOAH SHACHTMAN

THE FULL-TILT FLYING MACHINE

TWENTY YEARS IN DEVELOPMENT, THE NEW OSPREY TILT-ROTOR FLIES FASTER AND FARTHER THAN ANY HELICOPTER AND GOES PLACES AIRPLANES NEVER COULD BY BILL SWEETMAN

HOW IT FLIES

AS THE OSPREY LIFTS OFF in helicopter mode **(1)**, the onboard computers, commanded by the pilot, control it by changing the pitch of the rotor blades—the angle at which they bite into the air as they spin around the hub. To accelerate the MV-22 into airplane-like flight **(2)**, the **nacelles** rotate forward, and the **prop-rotors** transition from generating lift and controlling the direction of the aircraft to simply creating forward thrust. At higher speeds the air flowing over the **wings** keeps the Osprey aloft. The helicopter controls slowly lock out, and the Osprey flies like a conventional airplane **(3)**, controlled by the **ailerons** on the wings and the **rudders** and **elevators** on the tail.



Q: WHY DID IT CRASH IN TESTING?

PROP-ROTORS The MV-22's 38-foot-diameter prop-rotors are more than twice the size of any propeller but smaller than many helicopter rotors. The inner sections are twisted like prop blades; the outer sections are straight like rotors. The counter-rotating blades negate each other's rotational forces, eliminating the need for a tail rotor to keep the fuselage straight.

WINGS To support powerful engines and big whirling rotors at the tips, the wings are made almost entirely of superstrong and expensive carbon-fiber composite material, which also helps suppress vibrations.

FORWARD FLIGHT Cruising at 275 mph, the aircraft far exceeds conventional helicopters in speed and range

COCKPIT with controls that change function based on the Osprey's flight mode

Night-vision sensor

Midair refueling probe

FUSELAGE Up to 24 Marines or 20,000 pounds of gear fit into the 864-cubic-foot interior. The intense downdraft from the rotors makes it impossible for troops to exit from the side, so they slide down ropes from the rear ramp. Likewise, troops can't fire machine guns from the side doors in the classic helicopter style, in part because the engines and propellers block the field of fire. Instead there's a single gun in the rear.

SPECS: MV-22 OSPREY

WHAT: First tilt-rotor aircraft
SIZE: 22.1 ft. (h), 84.6 ft. (w), 57.4 ft. (l)
WEIGHT: 27.5 tons
COST: $71 million
AIR SPEED (CRUISING): 275 mph
RANGE: 500 miles with one refueling
MISSION: Marine Corps assault support
MANUFACTURER: Bell Helicopter and Boeing
VARIANTS: CV-22 (Air Force special-ops missions)
ENTERING SERVICE: Late 2007

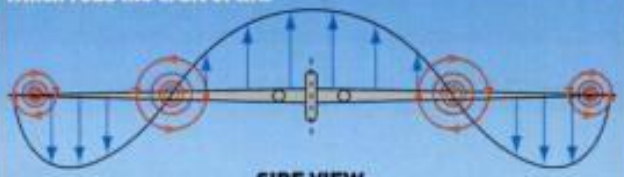
THE MV-22 SUFFERED four crashes in testing that killed 30 Marines. The worst, in Marana, Arizona, in April 2000, killed 19. The cause: a phenomenon called vortex ring state (VRS), which is specific to helicopters. VRS happens when a copter descends rapidly with little or no forward air speed. The aircraft slips into the wake created by its own blades, and the churned-up air begins to recirculate through the rotor. Caught in this vortex of disturbed airflow, the copter loses lift and begins to sink. Pouring on power—a pilot's instinctive response to a falling craft—only disturbs the air further, making the bird drop faster.

VRS is so dangerous to tilt-rotors because the effect can be asymmetrical: If only one rotor experiences VRS, the aircraft will quickly roll out of control instead of merely sinking more quickly. The Osprey now has a VRS warning system and its pilots are trained to recognize the signs of VRS and to escape by simply easing the Osprey forward. But critics argue that this Achilles' heel compromises the Osprey's ability to navigate combat zones with the speed necessary to avoid attack.—B.S.

VORTEX RING STATE

Typically, the air forced down by the rotor "rolls up" to create a vortex below the aircraft.

In VRS, a copter descending too steeply enters that vortex, which robs the craft of lift.



SIDE VIEW

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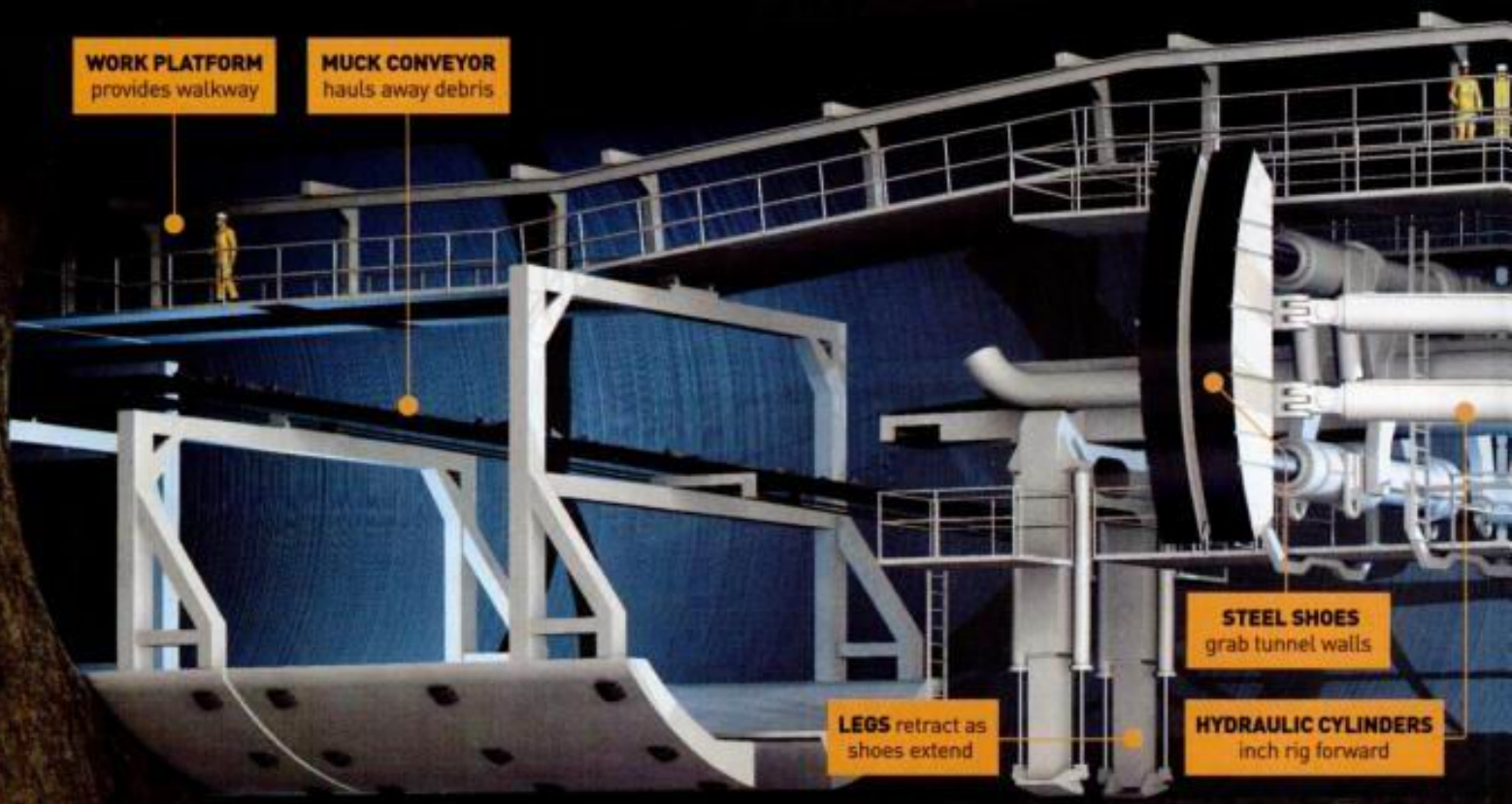
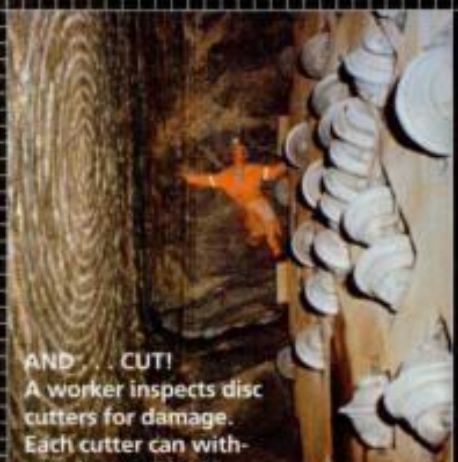


THE TUNNEL MONSTER

NEXT YEAR, THE WORLD'S BIGGEST DRILL WILL CHEW A 47-FOOT-WIDE HOLE



AND . . . CUT!
A worker inspects disc cutters for damage. Each cutter can withstand up to 70,000 pounds of force as it bores through rock.

CUTTING

The **teeth** of the MB471-316 machine, now under construction, are 85 rolling steel disc cutters meticulously arranged on a **cutter face** (also made of steel) that rotates up to seven times a minute. The cutters, each nearly two feet long, will be among the largest ever made for tunnel digging. They spin freely to carve concentric circles [left] in the rock and produce more than 1,600 tons of rubble an hour. The face of the drill contains a small door through which workers can crawl to replace the 15 or so cutters that wear out every day.

REMOVAL

As the pieces of cut rock fall to the ground, **muck scoops** in the side of the head collect and deposit them into **chutes** [facing page]. As the head rotates upward, the debris falls onto a **muck conveyor** belt, which ferries it to the rear of the machine.

MOVEMENT

Hydraulic cylinders attached to the drill's spine propel it forward like an inchworm. To stabilize the machine as it crawls, steel **shoes** push outward, gripping the tunnel walls, while two retractable **legs** lift off the floor.

Q: HO

PopSci ON THE WEB See other tunneling machines in action at *popsci.com/tunnel*.

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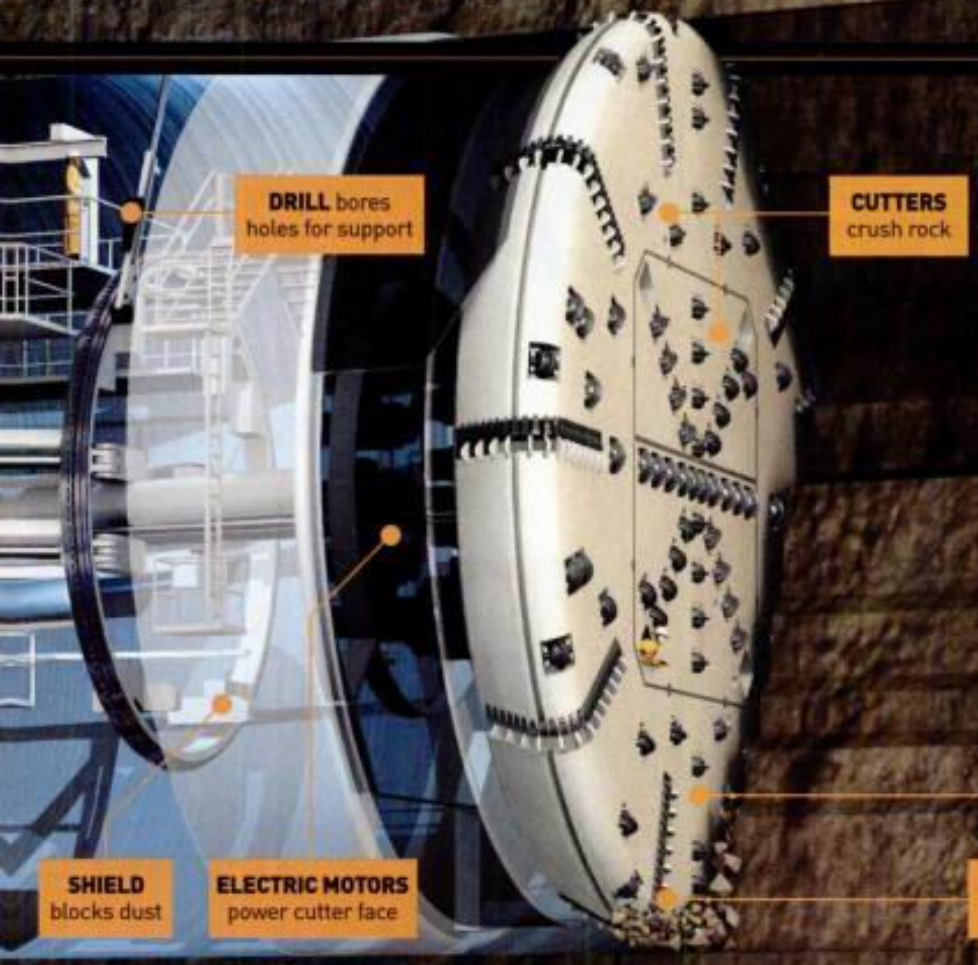


SPECS: MB471-316

WHAT: World's largest hard-rock drill
COST: More than $31 million
SIZE: 80 feet long, 47 feet across
WEIGHT: 2,000 tons
SPEED: 10 feet an hour
NECESSARY MANPOWER: 230 workers

WHAT'S IT FOR?

Canada wants more power. To get it, Ontario Power Generation is creating a $1-billion, 6.5-mile-long tunnel beneath the Niagara River that will divert 132,000 gallons of river water per second to a hydroelectric plant in Ontario. The result: enough juice to light an extra 160,000 homes a year.

UNDER THE NIAGARA RIVER LIKE A HAND DRILL IN SHEETROCK

BY SARAH Z. WEXLER

POWER

Fifteen **electric motors** supply the machine with a record-breaking 6,375 horsepower. The drill is tethered to a cable carrying 13,800 volts.

STABILITY

As the machine excavates, two **drills** just behind the cutters bore into the unsupported roof. Workers fill the holes with bolts and grout, turning the rock into a protective canopy.

CONTROL

The machine operator sits in a cabin [not shown] located at the center of the machine, where he controls all its functions, including its speed and direction. Video cameras give people above- and belowground a full view of the drill and the hole.

BACKUP

The machine tows nearly 800 tons of backup equipment through the tunnel, including trailers for electrical support systems, firefighting supplies and even a lunchroom.

HOW DOES IT STAY ON TRACK?

DIGGING MASSIVE HOLES is a precise science. A drilling rig must bore to within inches of a land surveyor's specifications. To stay on track, the driver receives constant feedback from the surveyor, who calculates the rig's precise location by bouncing laser beams off targets mounted on the back and front ends of the rig. Beyond a mile, however, the air becomes so thick with dust that it scatters the beams, forcing the rig to rely on preprogrammed coordinates to navigate the terrain.—DARRIN BURGESS

THE NEXT SPACE THRUSTER

ROCKETS BURN FOR MERE MINUTES. THIS ENGINE RUNS FOR YEARS. SENDING PROBES TO NEPTUNE AT 10,000 MILES AN HOUR BY MICHAEL MOYER

NASA'S ION ENGINE

1. CHARGE THE FUEL

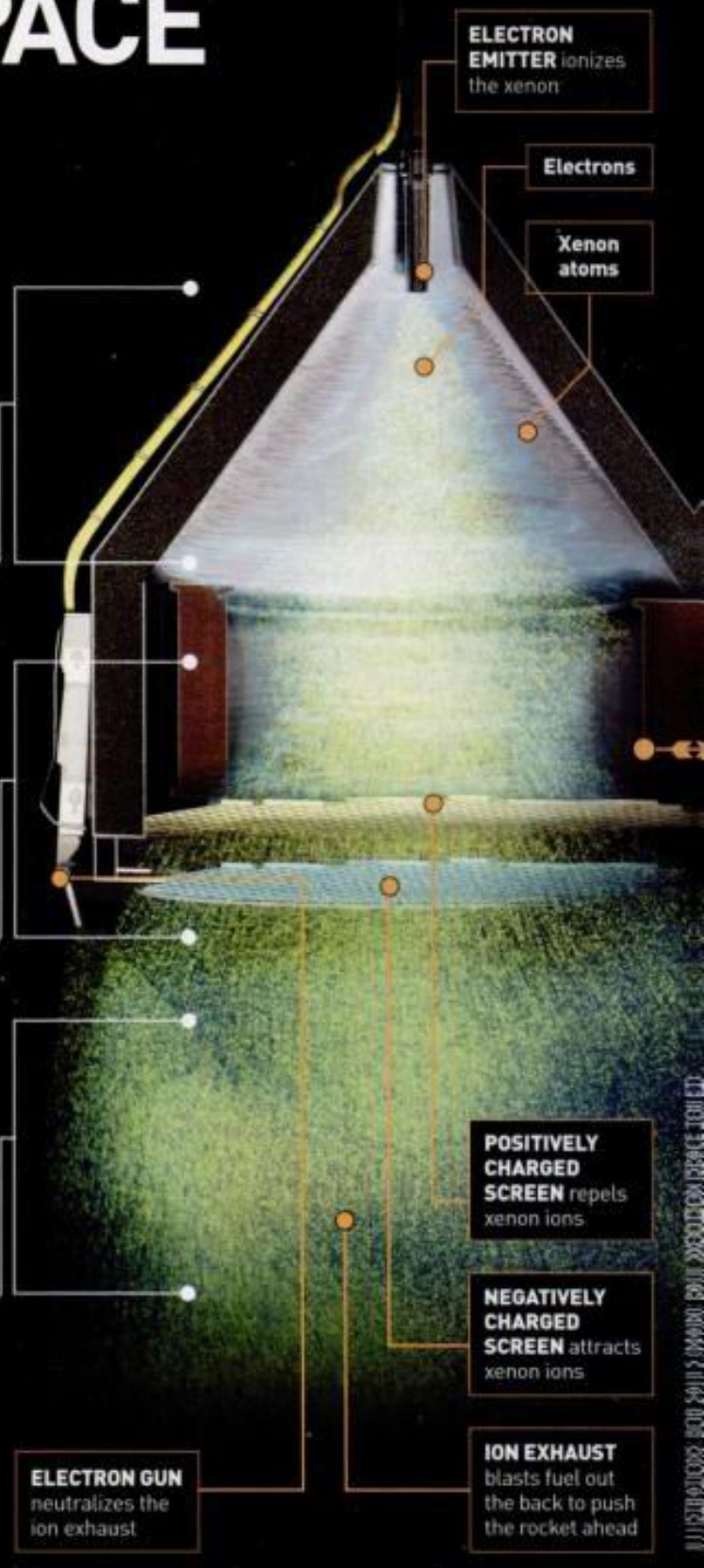
Xenon is an inert gas, seemingly useless for rocketry. Before it's used as fuel, the engine must convert it into an electrically charged gas, also called a plasma. An **electron emitter** fires **electrons** at the **xenon gas**. When an electron hits a xenon atom, it strips off an additional electron from the atom's shell to create a positively charged xenon ion.

2. ACCELERATE THE GAS

Once the xenon is charged, it moves through two grids held less than a millimeter apart. The first is a **positively charged grid** that repels the plasma. The second is a **negatively charged grid** that attracts it. Net effect: The xenon ions shoot downstream and out the back of the engine at tens of thousands of miles an hour.

3. SPEED AHEAD

The force of this high-speed plasma propels the spacecraft forward, like a kid on a skateboard shooting a fire extinguisher. Although at any moment the amount of thrust is small—equivalent to the weight of four quarters—the net effect of this thrust continuously applied for years at a time could accelerate a spacecraft to more than 32,000 miles an hour.



MYSTERIES OF EVERYDAY LIFE®

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SOLAR PANELS power the spacecraft while it's in the inner solar system

Antennas

XENON TANKS store years' worth of fuel

ION THRUSTERS burn continuously for three to five years on the way to Neptune. By the time the spacecraft arrives, it's cruising at nine miles a second

NUCLEAR GENERATORS produce energy for the thrusters when the spacecraft is far from the sun

SPECS: NEPTUNE ORBITER

WHAT: Artist's conception of proposed craft destined for Neptune, powered by ion propulsion thrusters. The design is based on NASA's now-canceled *Jupiter Icy Moons Orbiter*
LENGTH: 192 feet
THRUST: 0.5 pound
TOP SPEED: 32,000 mph
MISSION DURATION: 11 years
TOTAL DISTANCE: 3.5 billion miles

HOW A TOILET WORKS . . . IN SPACE

The space shuttle's toilet uses a vacuum much like the toilets on airplanes. But in zero gravity, astronauts must use straps and levers to create a tight seal between their backside and the bowl. A vacuum hose captures urine. Wastewater is ejected into space, but solids are drained, compressed, and stowed until the ship returns to Earth. On future multiyear missions, waste will be used to fertilize onboard crops.—DARRIN BURGESS

STRAP IN For when nature calls

THE $150,000 WATCH

PORSCHE'S LATEST CHRONOGRAPH IS THE FIRST WATCH WITH A DIGITAL DISPLAY THAT'S DRIVEN BY SPRINGS AND GEARS. HERE'S A LOOK AT A FEW OF ITS 800 PARTS

BY JONATHON KEATS

PORSCHE DESIGN INDICATOR

TIMEKEEPING

The Porsche's timekeeping mechanism is similar to other mechanical watches but is very accurate and durable, thanks to its precise design and assembly. The slow release of tension from a wound **mainspring** [facing page] supplies the watch's power. As the mainspring uncoils, gears transfer its energy to a **balance wheel**, which converts the energy to measured beats by rotating back and forth at a set rate (28,800 times an hour, or four times a second) like a small pendulum. This moves the **escape wheel**, the first of a number of gears that reduce those beats to one per second. These drive the second hand, which triggers the minute and hour hands.

WINDING

A freely spinning **rotor** weighted on one side with palladium-gold alloy moves in circles around the case as the wearer swings his arm. That circular motion winds the watch's springs through a series of gears.

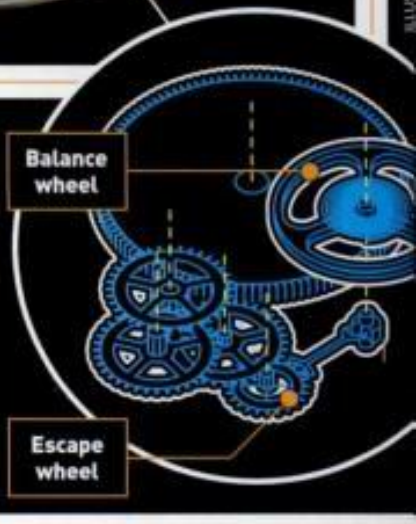
ILLUSTRATIONS: L-DOPA; PHOTOGRAPHS, FROM TOP: COURTESY ETERNA SA (2)

WHY IS IT $150,000?

In short, "complications"—mechanisms that do anything other than tell time. Watchmakers innovate by creating new ones, such as the Porsche's digital display and power-reserve gauge, or by packing in several. The most expensive modern watch, Vacheron Constantin's $1.5-million Tour de l'Ile [left], has 16, including sky and moon charts.

SPECS: PORSCHE DESIGN INDICATOR

SIZE: 1.9 in. (w), 0.7 in. (h)
WEIGHT: 4.86 oz.
PRICE: $150,000
CASE MATERIAL: Titanium
INDIVIDUAL PARTS: About 800
NUMBER MADE: 40 (in 2005)
YEARS IN DEVELOPMENT: 4
NEW COMPLICATIONS: 2
ACCURACY: Within 4 seconds a day



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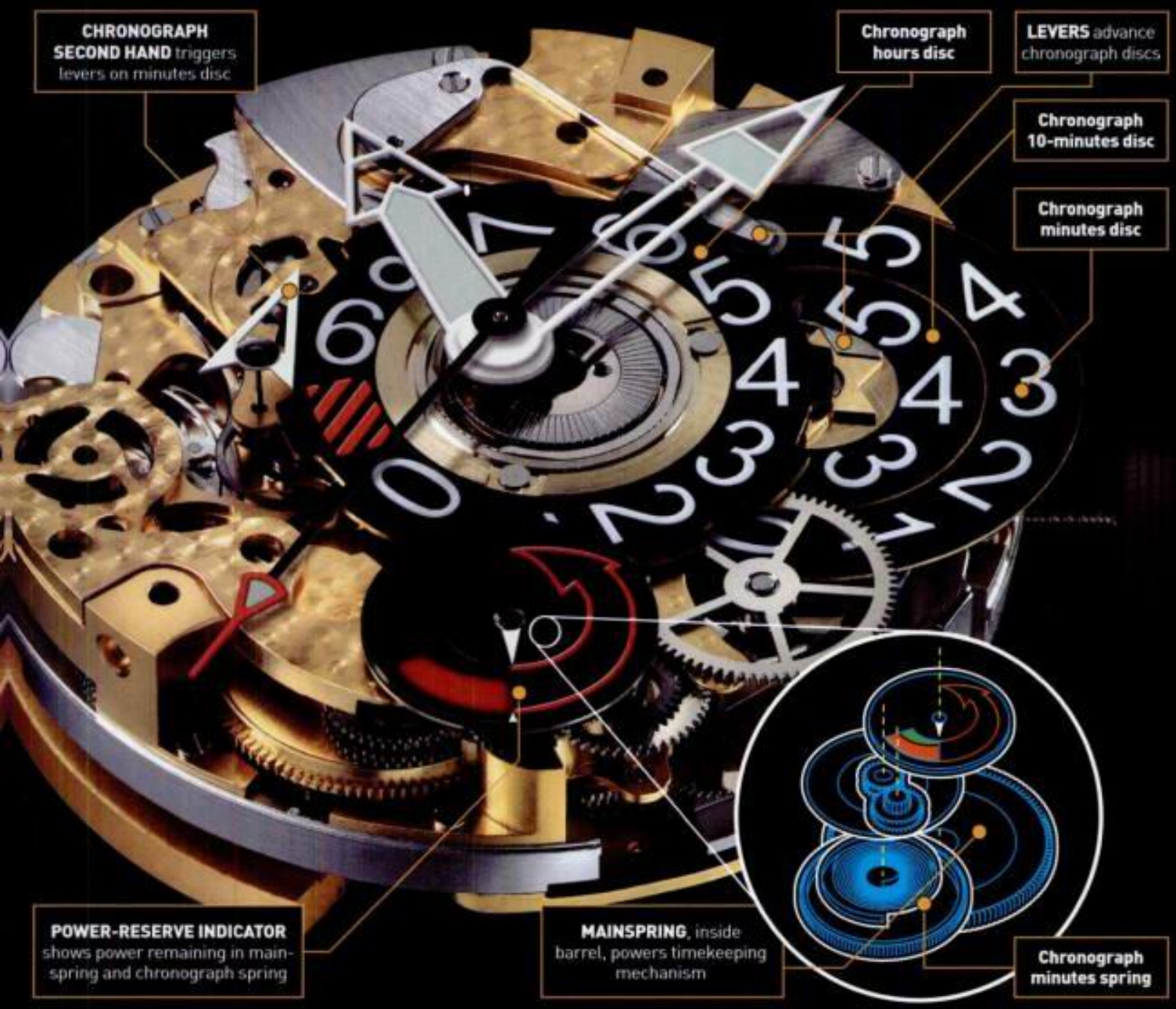

CHRONOGRAPH

A chronograph is like a stopwatch—it tracks elapsed time up to 10 hours. The Porsche is the first mechanical watch with a digital display: numbered dials instead of hands to show hours, minutes and seconds passed. A separate spring drives each dial, and each full rotation of the chronograph's **second hand** lifts a **lever** and releases the **minutes disc** to advance one number almost instantly. That resets the lever for another circuit. Each full rotation of the minutes disc operates a similar lever under the **10-minutes disc**, which in turn advances the **hours disc**.

POWER RESERVE

The **power-reserve indicator** shows you how long the watch will run without additional winding. Typically, a gear connected to the **mainspring** turns a gauge as the spring wears down. But the Porsche has three additional springs for the chronograph. When the chronograph is on, the spring turning the minutes disc (which makes 600 rotations in 10 hours) will run out before the timekeeping spring does. So the watch automatically switches to monitoring the chronograph while it is running—a first in watchmaking.

HOW A $10 WATCH TELLS TIME

Nonmechanical watches, cheap and pricey alike, measure time with quartz, a mineral that can be cut to vibrate at a predictable 32,768 times per second when fed a charge. Circuits or gears translate the vibrations to seconds.—DARRIN BURGESS

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THE FLYING LUXURY HOTEL

Tomorrow's cruise ship will sail through the air, not the water

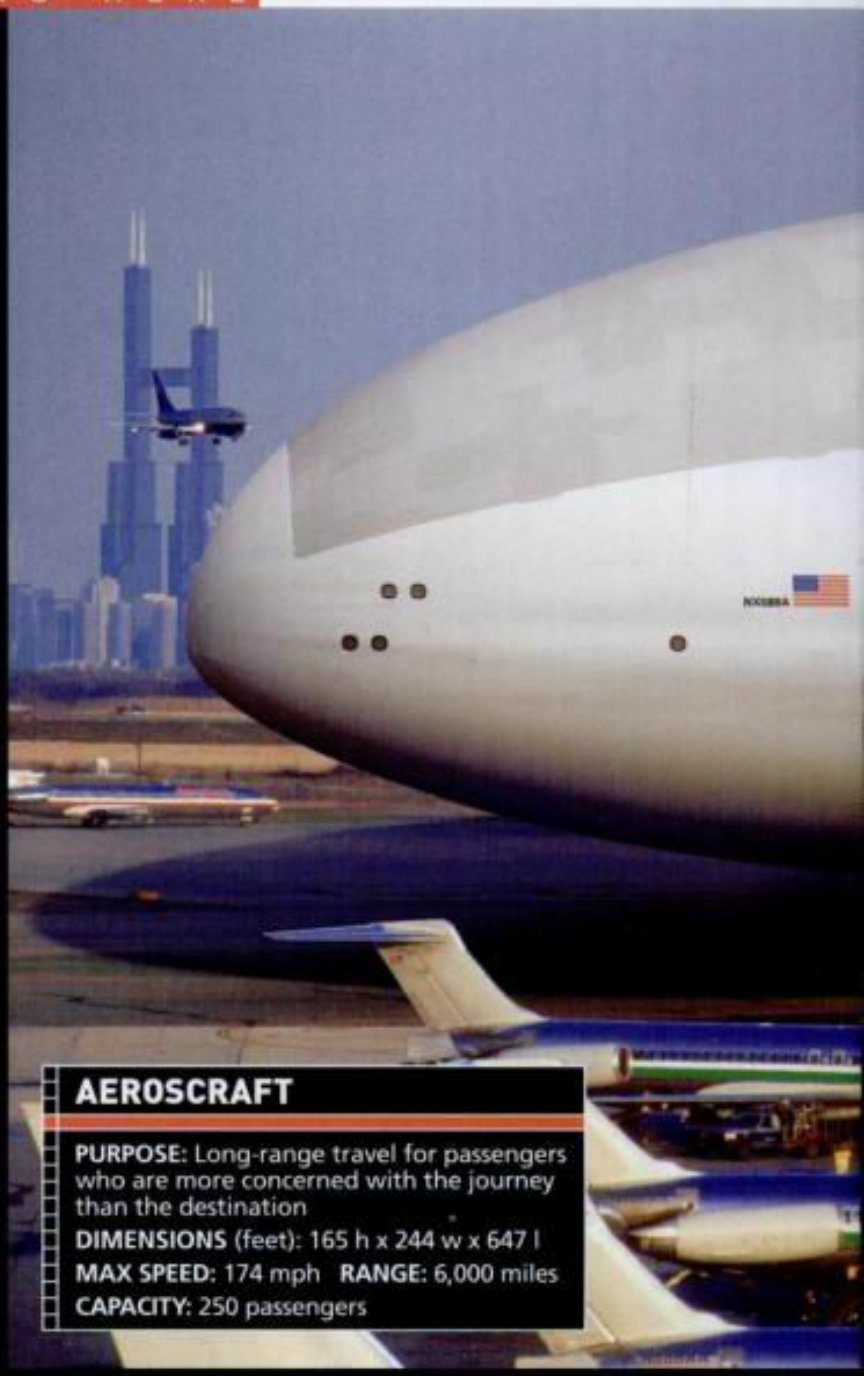
THIS IS NOT A BLIMP. It's a sort of flying *Queen Mary 2* that could change the way you think about air travel. It's the Aeroscraft, and when it's completed, it will ferry pampered passengers across continents and oceans as they stroll leisurely about the one-acre cabin or relax in their well-appointed staterooms.

Unlike its dirigible ancestors, the Aeroscraft is not lighter than air. Its 14 million cubic feet of helium hoist only two thirds of the craft's weight. The rigid and surprisingly aerodynamic body—driven by huge rearward propellers—generates enough additional lift to keep the behemoth and its 400-ton payload aloft while cruising. During takeoff and landing, six turbofan jet engines push the ship up or ease its descent.

This two-football-fields-long concept airship is the brainchild of Igor Pasternak, whose privately-funded California firm, Worldwide Aeros Corporation, is in the early stages of developing a prototype and expects to have one completed by 2010. Pasternak says several cruise ship companies have expressed interest in the project, and for good reason: The craft would have a range of several thousand miles and, with an estimated top speed of 174 mph, could traverse the continental U.S. in about 18 hours. During the flight, passengers would peer at national landmarks just 8,000 feet below or, if they weren't captivated by the view, the cavernous interior would easily accommodate such amenities as luxury staterooms, restaurants, even a casino.

To minimize noise, the aft-mounted propellers will be electric, powered by a renewable source such as hydrogen fuel cells. A sophisticated buoyancy-management system will serve the same purpose as trim on an airplane, allowing for precise adjustments in flight dynamics to compensate for outside conditions and passenger movement. The automated system will draw outside air into compartments throughout the ship and compress it to manage onboard weight.

The company envisions a cargo-carrying version that could deliver a store's worth of merchandise from a centralized distribution center straight to a Wal-Mart parking lot or, because the helium-filled craft will float, a year's worth of supplies to an offshore oil rig. "You can land on the snow, you can land on the water," Pasternak says. "It's a new vision of what can be done in the air."—JOSHUA TOMPKINS



AEROSCRAFT

PURPOSE: Long-range travel for passengers who are more concerned with the journey than the destination
DIMENSIONS (feet): 165 h x 244 w x 647 l
MAX SPEED: 174 mph **RANGE:** 6,000 miles
CAPACITY: 250 passengers

▲ LIFTOFF! Even though the Aeroscraft dwarfs the largest commercial airliners, it requires less net space on the ground than any plane because it doesn't need a runway. The airship takes off and lands like a helicopter: straight up and down.

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Jet-engine air intakes

Stateroom windows

NOT A CHANCE — BOOK YOUR TICKET

ODDS OF PRODUCTION

QUITE A VIEW On a pressurized plane, windows like these would explode outward . The Aeroscraft does not fly high enough to need pressurization.

LET ME DOWN EASY A ring of inflatable air cushions on the bottom acts as the landing gear.

Propeller array

Jet-engine exhaust

Air cushions

ILLUSTRATIONS: JOHN MacNEILL; BACKGROUND PHOTOGRAPH (TOP): PETER SCHULZ/INDEX STOCK

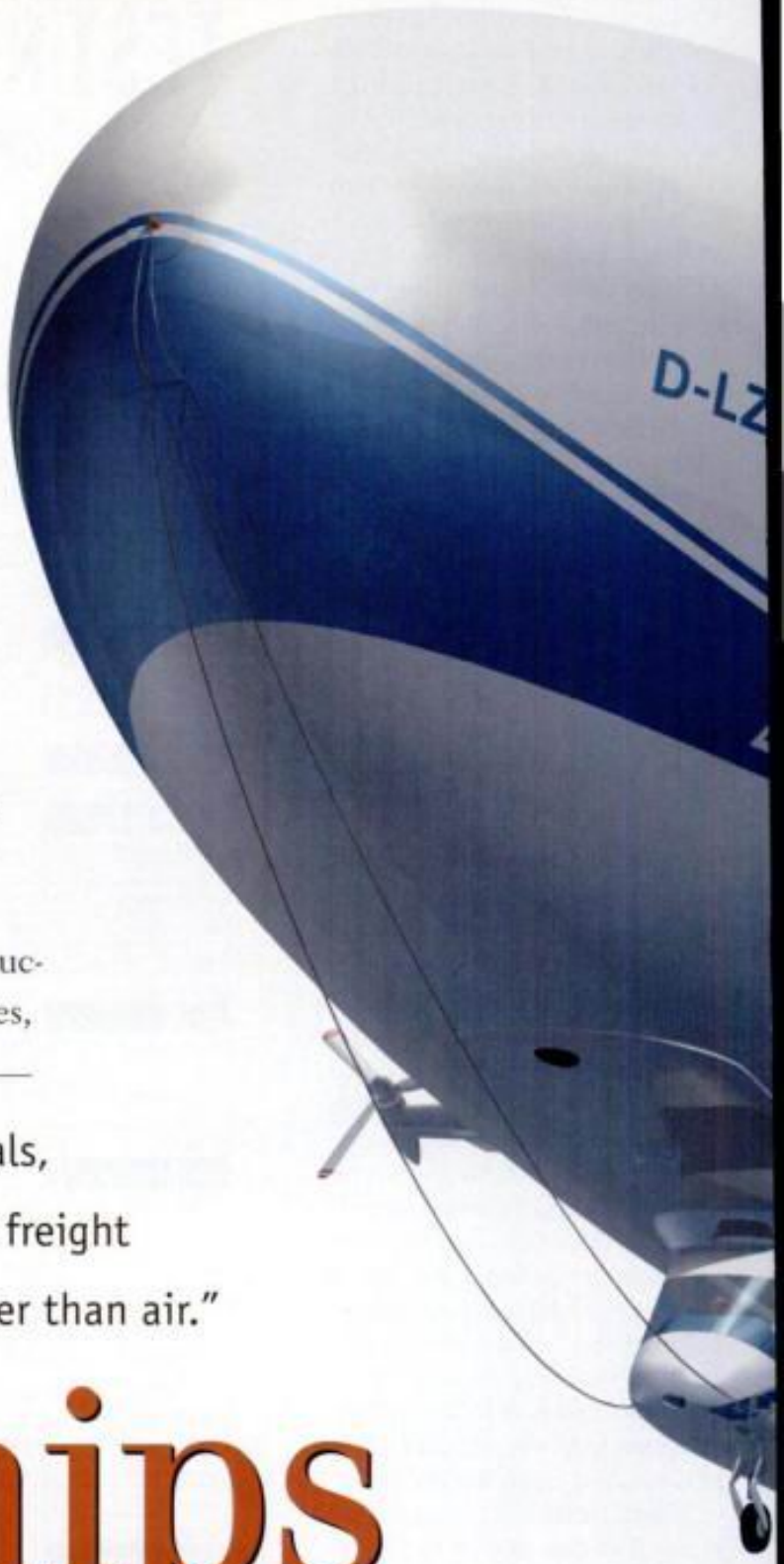
PopSci
See more pictures at popsci.com/aeroscraft

By Christopher Miller

THE AGE OF AIRSHIPS ended in 1937, when the 245-meter-long German Zeppelin *Hindenburg* ignited and crashed at Lakehurst, New Jersey. Or . . . did it end?

Thanks to a healthy economy, cheaper and stronger materials, and falling design costs, airships seem about to rise again, phoenix-like, from the *Hindenburg*'s ashes. Led by the doyen itself—Zeppelin and its Zeppelin NT, which is already flying in Europe—at least seven companies are vying to return airships to the skies for hauling large cargo or for transporting passengers in luxury.

Unlike blimps, which have minimal structures to support their gondola and engines,



Thanks to a revolution in materials, the latest catchphrase for future freight and passenger air travel is "lighter than air."

Airships Rise Again

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At the Zeppelin NT's heart are carbon-fiber composite frames attached to three aluminum longerons. Kevlar fiber is used to brace the frames. This semi-rigid design reduces total weight without compromising strength. Fins at the rear of the airship connect to the frame for added strength.

Zeppelin NT

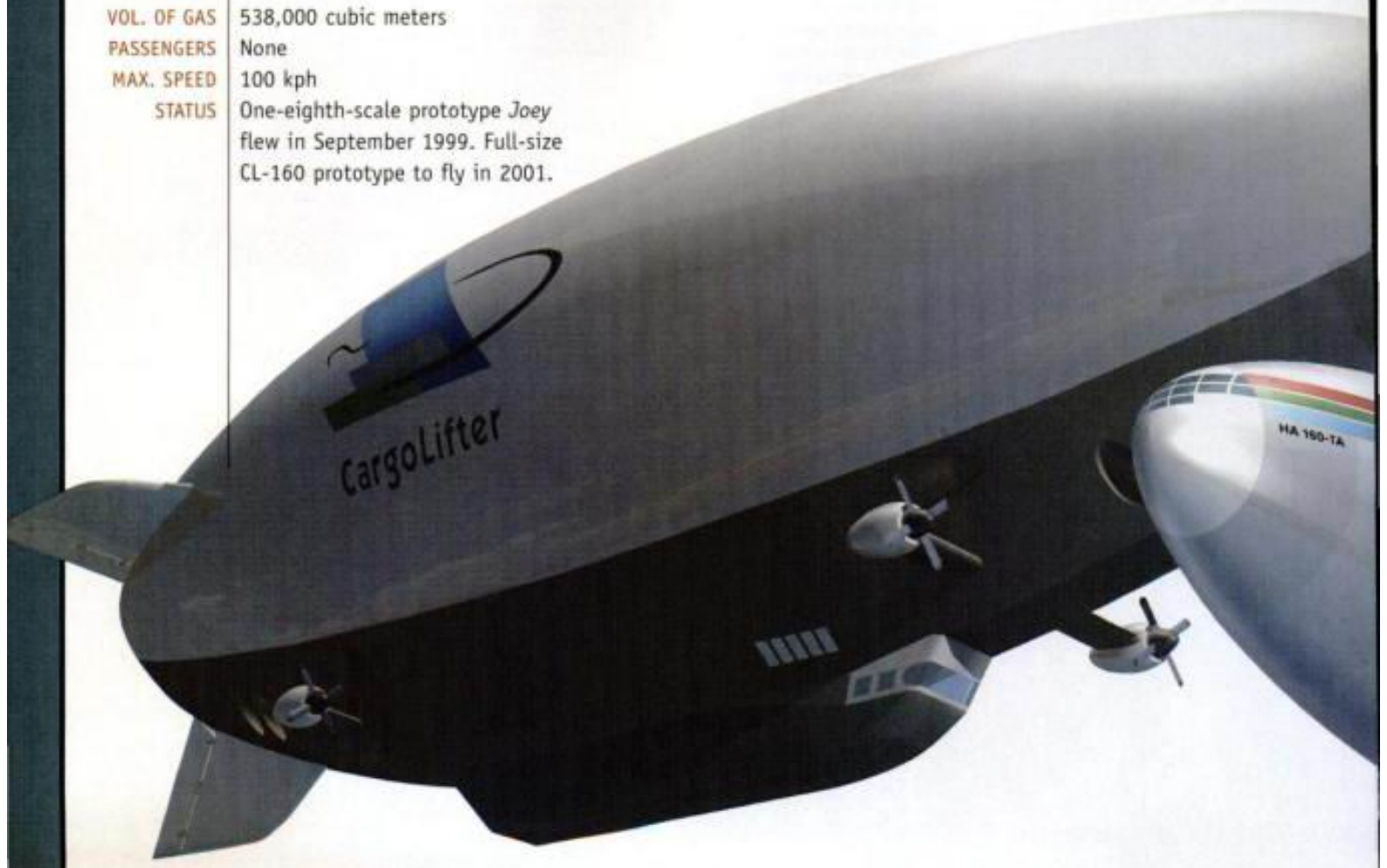
COMPANY	Zeppelin Luftschifftechnik, Friedrichshafen, Germany
LENGTH	75 meters
VOL. OF GAS	8,200 cubic meters
PASSENGERS	12
MAX. SPEED	115 kph
STATUS	In-flight certification by FAA and agencies of other countries

Commercial certification for the NT (for "new technology") is anticipated by early 2001. The NT continued its series of certification flights in Germany this past August. Skyship Cruises of Lindau, Switzerland, will be the first to take delivery of an NT in May 2001.

ILLUSTRATION JOHN MACNEILL

CargoLifter CL-160

COMPANY	CargoLifter, Raleigh, North Carolina, and Frankfurt, Germany
LENGTH	260 meters
VOL. OF GAS	538,000 cubic meters
PASSENGERS	None
MAX. SPEED	100 kph
STATUS	One-eighth-scale prototype *Joey* flew in September 1999. Full-size CL-160 prototype to fly in 2001.



With its ability to lift 160 metric tons, the CL-160 belongs on muscle beach. The airship is heart-shaped to decrease wind resistance. It will be housed outside Berlin in the world's largest hangar—three football fields long and about a football field high—which was to have been completed by the end of 2000. The United Nations plans to use CargoLifter for such humanitarian efforts as bringing hospitals to remote areas.

airships have extensive skin-covered interior frames. This means they can carry more weight and travel faster than blimps.

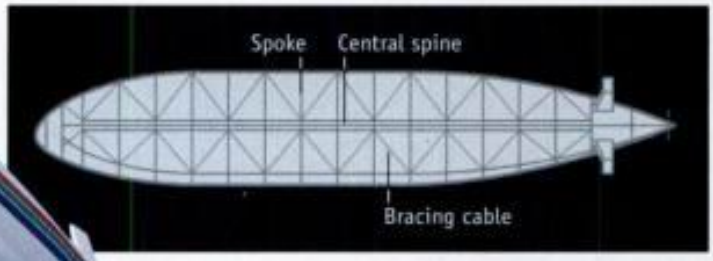
An airship offers some advantages over the airplane as well. "It's an efficient vehicle; it doesn't need energy to float," says airship historian and expert J. Gordon Vaeth. That means less costly fuel. CargoLifter, an airship company in Raleigh, North Carolina, expects its services to average one-third less than cargo plane costs.

Vaeth cites another airship plus: "It can carry immense cargoes and bring those cargoes into and out of remote areas without runways." For example, an airship could transport all the necessary equipment to a site to build a dam or provide needed medical aid, food, and water for an isolated village. CargoLifter's CL-160 airship, for instance, will be able to lift 160 metric tons. This translates into 70 Chevy Suburbans; a Boeing 747 would have difficulty carrying 45. In fact, CargoLifter could drop an entire factory facility into a remote area. "We're going to

Turtle Airship

COMPANY	Turtle Airship, Olympia, Washington
LENGTH	110 meters
VOL. OF GAS	Undetermined
PASSENGERS	30
MAX. SPEED	Unknown yet
STATUS	In development

Carbon fiber and a geodesic-shape exoskeleton form the Turtle's solid, rather than fabric, exterior. The hard shell means that this airship does not need a protective hangar, unlike fabric skins; this also permits water landings. The ship will be a tourist vehicle, in addition to providing rescue support.



A central axle supports the modular wheel-and-spoke design of the Hamilton's internal structure. The wheels become smaller as they taper toward the ends of the airship. Helium-filled Tedlar bags fit between the spokes. The spine is pressurized with air to control pitch. A prototype was flown in 1999. The final version of the 160-meter ship would cruise at 90 kph.

Hamilton Airship

COMPANY	Hamilton Airship, Bryanston, South Africa
LENGTH	160 meters
VOL. OF GAS	46,100 cubic meters
PASSENGERS	48
MAX. SPEED	145 kph
STATUS	Prototype built and flown, with plans for a larger version in 2001

change the way people design [large] projects," predicts Tom Boyle, vice president of marketing and logistics at CargoLifter.

Richard van Treuren, a space shuttle engineer and a member of the Lighter-Than-Air Society—a group of airship aficionados—adds: "The big selling point of a buoyant craft over an airplane is that if the engines stop, you don't die."

Others are embracing the potential of airships for luxury travel. Jonathan Hamilton of Hamilton Airship in Bryanston, South Africa, envisions cruise ships of the sky. With 24 rooms, a library, and a gym, the Hamilton Airship would be like a flying Four Seasons hotel blending with a Carnival luxury liner. The airship would cruise a mere 150 meters off the water from New York to London in 48 hours.

All these auspicious plans take place against a background of improved design and materials. Computer-aided design has cut development costs,

www.popsci.com The case for cycloidal propellers

CooperShip

COMPANY	CooperShip Industries
LENGTH	231 meters
VOL. OF GAS	1.5 million cubic meters
PASSENGERS	2,000
MAX. SPEED	278 kph
STATUS	In design stages

Holland Navigator

COMPANY	Rigid Airship Design, Lelystad, Netherlands
LENGTH	180 meters
VOL. OF GAS	75,000 cubic meters
PASSENGERS	240
MAX. SPEED	148 kph
STATUS	RA-180 prototype ready in 2001

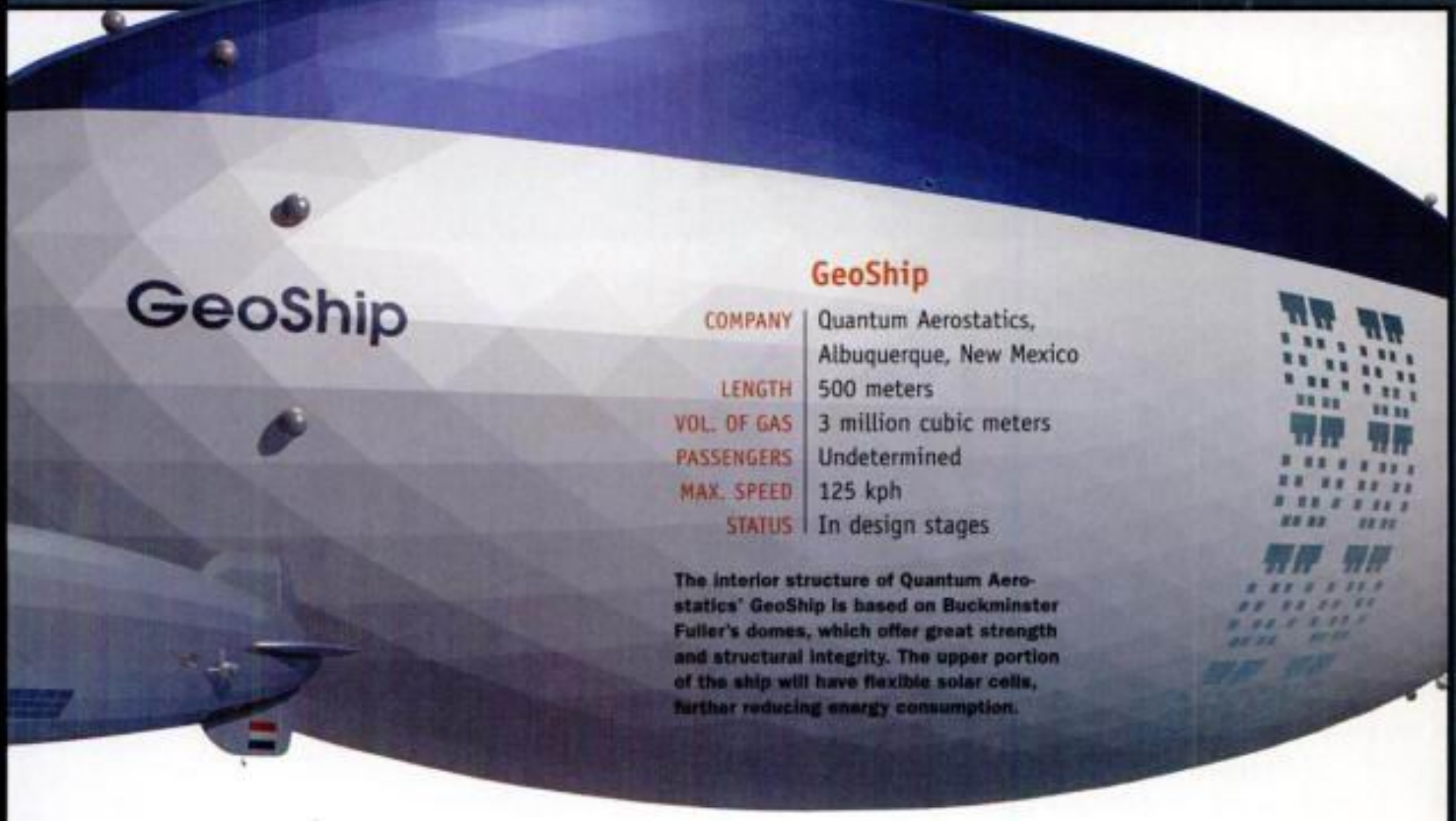
This airship will be a modern look-alike of the Zeppelins that flew during World War I. The Navigator will be used primarily for luxury travel. The company, Rigid Airship Design, has proposed building a hangar in Lelystad, Netherlands.

The CooperShip is shaped like an equilateral triangle. Inside, 15 helium-filled cells permit the airship to carry 10 times the payload of a 747.

while aramid fibers like Tedlar and Kevlar reduce manufacturing expenses as well as weight. Unlike the coated cotton and latex layers once used to retain helium, the ballonaise—the envelope inside the airship—is now covered with thin plastic laminate to prevent that Houdini-like molecule, helium, from escaping. Fabric materials makers such as TCom in Columbia, Maryland, laminate Tedlar and Mylar layers onto an airship's light polyester fabric exterior covering. "The life expectancy of our old fabric was one to two years. Tedlar will last for 10," says Bob Fowler, chief pilot at Airship Operations in Kissimmee, Florida.

Behind the wheel of a blimp www.popsci.com

At least one company has resolved the fabric issue by eliminating it. The Turtle Airship, from the company of the same name in Olympia, Washington, replaces the fabric outer skin with carbon fiber. "The exoskeleton is made of honeycomb panels as in a geodesic dome," says Darrell Campbell, the Turtle Airship's designer. On the inside of the dirigible, carbon fiber forms the framework. Kevlar cables



GeoShip

COMPANY	Quantum Aerostatics, Albuquerque, New Mexico
LENGTH	500 meters
VOL. OF GAS	3 million cubic meters
PASSENGERS	Undetermined
MAX. SPEED	125 kph
STATUS	In design stages

The interior structure of Quantum Aerostatics' GeoShip is based on Buckminster Fuller's domes, which offer great strength and structural integrity. The upper portion of the ship will have flexible solar cells, further reducing energy consumption.

The SkyCat 1000 relies on helium for 60 percent of its lift, while the other 40 percent comes from the elliptical design. Cushions at the base of the airship permit the SkyCat to land anywhere.

SkyCat 1000

COMPANY	Advanced Technologies Group
LENGTH	307 meters
VOL. OF GAS	2 million cubic meters
PASSENGERS	None
MAX. SPEED	204 kph
STATUS	Prototype flown, smaller version of the SkyCat 1000 will fly later this year

support the internal trusses much as with a suspension bridge, making up for some of the weight added by using carbon fiber on the exterior instead of fabric.

The interior "guts" of these helium-filled airships have changed too. Traditionally, airships use wood and steel cable for supports and gondolas. A lighter and stronger material has replaced each. Kevlar may be used to make the gondola, with aluminum supports to build the rigid structure. The Zeppelin NT has a graphite-epoxy frame combined with an aluminum support to provide a semi-rigid structure. The Turtle Airship uses Kevlar cables to support the interior gondola and decks.

Clearly, a lot must happen before airships become common sights in our skies. Vaeth estimates that creating a modern version of the Hindenburg would cost upward of a billion dollars. If companies leap the financial hurdles, there will be another obstacle: a lack of experienced airship pilots. Vaeth, who served on an airship in World War II, puts the experience into perspective: "Visualize yourself trying to drive a car that's a thousand feet long."

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BUILT TO FLY The mast mimics the bone structure of a bat's wing, with three segments. The middle one has two parallel struts and works like a two-boned forearm to increase flexibility. The upper "fingers" increase rigidity.

WING MIGRATION Because of the mast's changing shape, the sailcloth must be elastic, like the membrane of a bat wing. Current models use a polyurethane-coated knit cloth that's far more stretchable than conventional sailcloth.

THREE KEY FACTS

1. **Ninety-five percent** of intercontinental trade takes place by way of cargo ships.
2. **Oil has never been** as expensive as the nearly $71 a barrel it hit last year.
3. **New sail technology** could reduce ships' fuel consumption by up to 35 percent.

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WELCOME TO THE NEW AGE OF SAIL

Oversize kites, bat-wing sails—even blimps—may soon be pulling the world's cargo ships across the oceans

AIR CONTROL A hydraulic system raises and lowers the sails, which are housed in modules that are clamped to the deck and can be moved on and off the ship by crane.

DAVE CULP HAS A RADICAL VISION. He sees enormous diesel ships—cargo carriers and supertankers and luxury liners, vessels weighing tens of thousands of tons—hitched to giant kites and towed on their courses by ocean winds. He sees the ancient kite becoming a crucial technology of global trade, a tool to move goods and passengers cleanly and swiftly around the world.

It's a romantic idea. But Culp, a designer of recreational kitesails who has become the chief American proponent of a return to sail power, is far from alone.

Last year the German government handed almost $1 million to a start-up, SkySails, that has precisely the same long-term aim as Culp's company, KiteShip: to retrofit a substantial segment of the world's commercial fleet with huge fuel-saving kites. The large Swedish shipping company Wallenius Wilhelmsen recently announced plans to build the first zero-emissions cargo vessel, featuring 45,000 square feet of rigid sail. Denmark and Japan have similar initiatives under way, and in England an inventor named Richard Dryden has devised a retractable modular sail based on the structure and aerodynamic properties of a bat's wing.

Since World War I, when the first generation of oil-burning vessels arose from wartime submarine technology, oil has never been as expensive as the nearly $71 a barrel it reached last August. Ship fuel now costs about three times what it did just a few years ago and accounts for half of the average vessel's operating cost. Estimates of how much sail-

SAIL SYSTEM #1

THE BAT SHIP

THE VISION: Shipping companies purchase modular sails, which are fixed to the deck of a ship and used only when wind conditions are good. The 130-foot-tall structures, inspired by the properties of a bat wing, are rotated and trimmed based on information collected by a computer that monitors wind speed and direction.

THE VISIONARY: English biologist-turned-inventor Richard Dryden, 59, first conceived of his oddly-shaped masts and sails as an innovation for windsurfers but was motivated by concerns about global warming and waning oil reserves to target larger vessels.

THE BUSINESS PLAN: Since 2000, when Dryden received a government grant of about $80,000, he's built and tested scale models of his design on small craft near his home in southwestern England. "This rig solves most of the major problems that have been put forward against the reintroduction of sails on merchant vessels," he says. "It's retractable for poor wind conditions and passing under bridges, and it requires no additional crew members." Another benefit: The portability of the units would, in theory, allow businesses to lease the sails just for trips with ideal wind conditions and avoid a large up-front investment.

WHEN'S THE MAIDEN VOYAGE? Dryden is planning wind-tunnel tests for later this year and is seeking funding to build a larger prototype. If the money comes, he says, a sound rig is only five years away.

BY JEBEDIAH REED ILLUSTRATIONS BY KRIS HOLLAND

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BIG BIRD At 400 feet across and with 50,000 square feet of sail area, the KiteTug, which would fly at about 1,000 feet, is arguably the most technically ambitious kite ever proposed.

HANG TIME A three-man crew handles all the routing from a hanging capsule that contains a power supply, navigational computers and compact living quarters.

CRUISE CONTROL Air-speed and air-pressure sensors on the sail's surface trigger automatic trimming and steering and maximize lift and stability.

BOUND TO THE BOW To attach to a client ship, the KiteTug drops a tow line on deck that the crew attaches to the mooring bit at the bow.

assist technology could reduce fuel consumption range from 10 to 35 percent, depending on the ship, the route and the type of sail employed. But even 10 percent would be a significant leap forward in an industry in which engineers expend great efforts in seeking efficiencies of 1 percent or less in the design of propellers, hulls and engines. "Today improvements in fuel efficiency are coming in small increments. The obvious next step is to try to utilize wind power," says Per Brinchmann, a naval architect who designs ships for Wallenius Wilhelmsen and other lines. "It can be adopted quickly and retrofitted on existing vessels. There's still not much understanding of the potential there, but I think there could soon be several companies building sail systems for large vessels."

New environmental regulations, like ones in Europe that recently raised fines for heavy polluters, could also push companies into gear. The diesel fuel that large ships burn, known

THE NEW TRADE WINDS

ON A TYPICAL JOURNEY, a KiteTug might pick up a London-bound container ship off the coast of New York and tow it to the entrance of the English Channel. Hours later it meets up with a bulk carrier en route to Lisbon and then proceeds under its own power to connect with a Greek oil tanker headed for Miami. Finally, it tugs a cruise ship up the eastern seaboard, back to New York.

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1 CONTROL SYSTEM
HAL-3's brain, strapped to your back. The shoulder pack contains a Linux-based computer, a wireless LAN, motor-drivers and force-measurement software. Looks like a heavy load—buck up, Grandma!—but the frame bears most of the weight, says Sankai.

2 MOTORIZED JOINTS
Not handlebars, but four actuators, each consisting of harmonic drive gear, that attach at the knees and hip joints. Sankai promises no jerky, robot-like moves. Angle sensors measure torque and degree of angular movement at the joints.

3 FUEL SOURCE
A high-functioning exoskeleton hinges on a long-lasting power source. For now, HAL-3 is equipped with nickel metal hydride batteries, attached to the waist, that deliver juice for up to 3 hours of walking, or 1 hour of leg squats.

4 ROBO BONES
Made of plastic, lightweight aluminum alloy and chrome, the frame feels "like you're wearing ski boots," Sankai says. HAL-3 is custom-fit, but future models will be ready-to-wear.

5 MUSCLE SENSORS
Sensors strategically placed at key muscle points pick up signals traveling from the brain to the muscles. The exoskeleton's biofeedback system must perfectly match the user's intent. "Otherwise," says Pin, "the machine will be more of a hindrance than a help."

6 SOLE SUPPORT
The HAL-3 is not worn, it's ridden, "like a vehicle," says Sankai. The bulk of the machine's weight (about 44 pounds) is supported by two heel cups; floor reaction sensors placed inside custom-designed sneakers allow the computer to measure pressure under the feet.

CLONE, CLOSES SHOP /// 9.23.03 SPACE SAFETY COPS QUIT ALL NINE MEMBERS OF A NASA SPACE-SAFETY ADVISORY PANEL RESIGN AFTER SHARP POST-COLUMBIA >

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THE COAST GUARDIAN

Engineered to support U.S. special forces, the M80 Stiletto will be the Navy's fastest and smartest ship

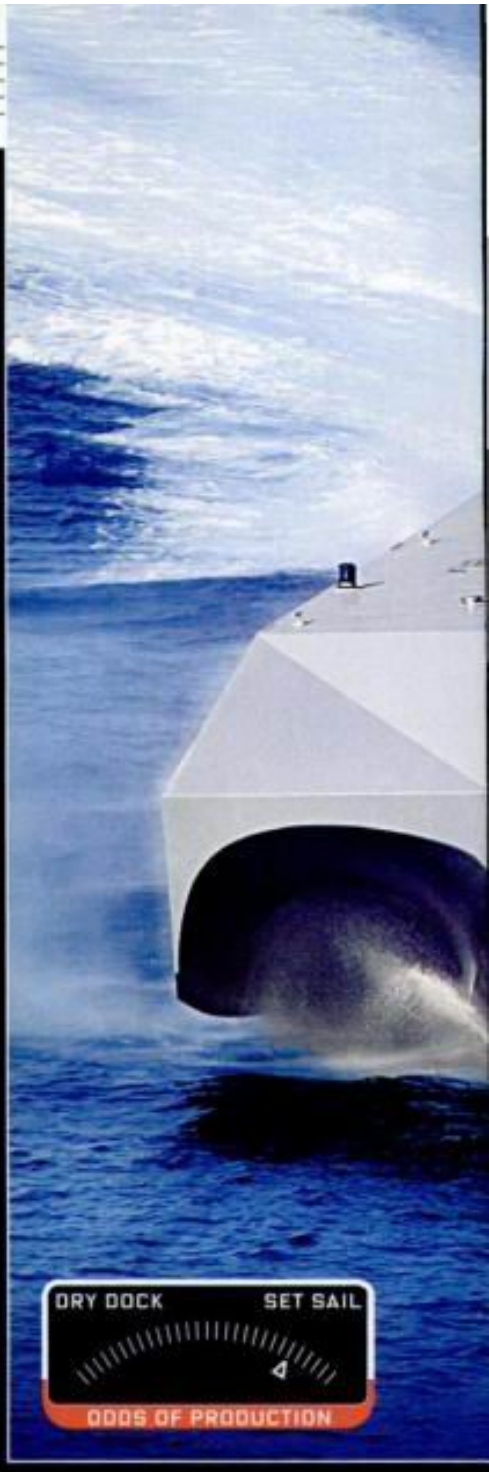
IF YOU'RE THINKING you've never seen a boat like this before, it's because there's never *been* a boat like this before. The fast and maneuverable M80 Stiletto could be the Navy SEALs' new ride. It is designed to operate close to shore and to back up its team with lifesaving information.

The Stiletto's "double-M" hull, the first of its kind, gives the boat the negligible 2.5-foot draft that enables it to operate in shallow waters. And at 40 feet wide, the craft is still stable in rough waves. But the hull's real specialty is velocity: As the Stiletto moves, air rushing through the four channels lifts the ship up, decreasing friction and enabling the craft to exceed 50 knots. That's speedboat fast.

And because it's made of superlight carbon fiber, the boat can carry 20 tons of cargo and still weigh less than 65 tons, equivalent to a similar-size steel boat. And the Stiletto has more than 2,000 square feet of usable interior space. What's in there? Well, beds, for one thing. The Stiletto will be a sort of high-tech mobile home for up to 12 Navy SEALs. When the ship drops off its team, the Stiletto's crew will set up its own cellular network, launching an unmanned aerial vehicle (UAV) to relay information between the boat and the SEALs. Instead of 10 to 20 pounds of communications gear, each SEAL will need only a small PDA-like device to receive an aggregated data stream managed by the ship's crew.

The Stiletto will also launch surveillance UAVs. And because it packs a clustered supercomputer with potentially more processing muscle than any other U.S. ship, the craft can combine all the surveillance data from a UAV into a 3-D or mosaic image in almost real time and send it directly to the team on shore.

The Stiletto was due to complete sea trials near San Diego in March. Commander Gregory Glaros, who is supervising the U.S. military–funded project, anticipates that the boat could be ready in less than a year. He won't comment on its chances of deployment but says he's optimistic that the Stiletto, with its $6-million price tag, will be attractive to the budget hawks in Washington. "In some D.C. neighborhoods," Glaros notes, "you couldn't get a 2,000-square-foot house for $6 million—much less one made entirely of carbon fiber."—**JOSHUA TOMPKINS**



BOB GRIESER; DIGITAL IMAGING BY ERIC HEINTZ

M80 STILETTO

PURPOSE: To deliver and support Navy SEAL operations
MANUFACTURER: M-Ship Company
DIMENSIONS (feet): 18.5 (h) x 40.5 (w) x 88.6 (l); 2.5 (draft)
WEIGHT: 45 tons (empty)
MAX. SPEED: More than 50 knots
RANGE: 750 miles
COST: $6 million for boat only; $10 million fully equipped
PROPULSION: Four 1,650hp Caterpillar diesel engines

PopSci ON THE WEB See more pictures of the M80 Stiletto, both in and out of the water, at *popsci.com/stiletto*.

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JOYRIDE
The M80 Stiletto undergoing its second round of sea trials in February

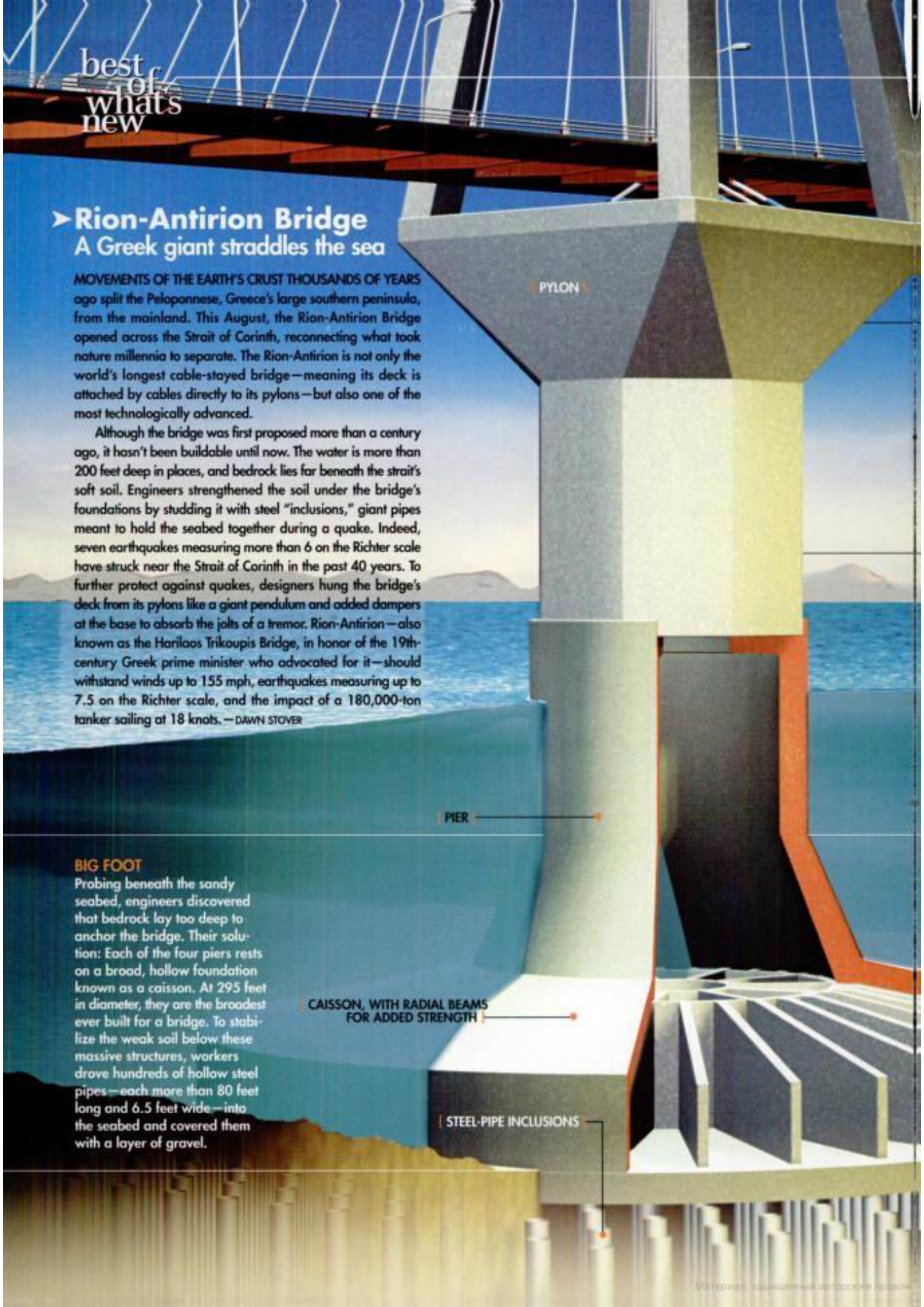
◀ **THE BACK DOOR** A boat launch in the Stiletto's rear is made specifically to accommodate one of the 35-foot rigid inflatable skiffs used by Navy SEAL teams.

▶ **NO, IT CAN'T FLY** But the Stiletto is light enough to hoist onto a cargo ship and transport anywhere in the world.

➤Rion-Antirion Bridge
A Greek giant straddles the sea

MOVEMENTS OF THE EARTH'S CRUST THOUSANDS OF YEARS ago split the Peloponnese, Greece's large southern peninsula, from the mainland. This August, the Rion-Antirion Bridge opened across the Strait of Corinth, reconnecting what took nature millennia to separate. The Rion-Antirion is not only the world's longest cable-stayed bridge—meaning its deck is attached by cables directly to its pylons—but also one of the most technologically advanced.

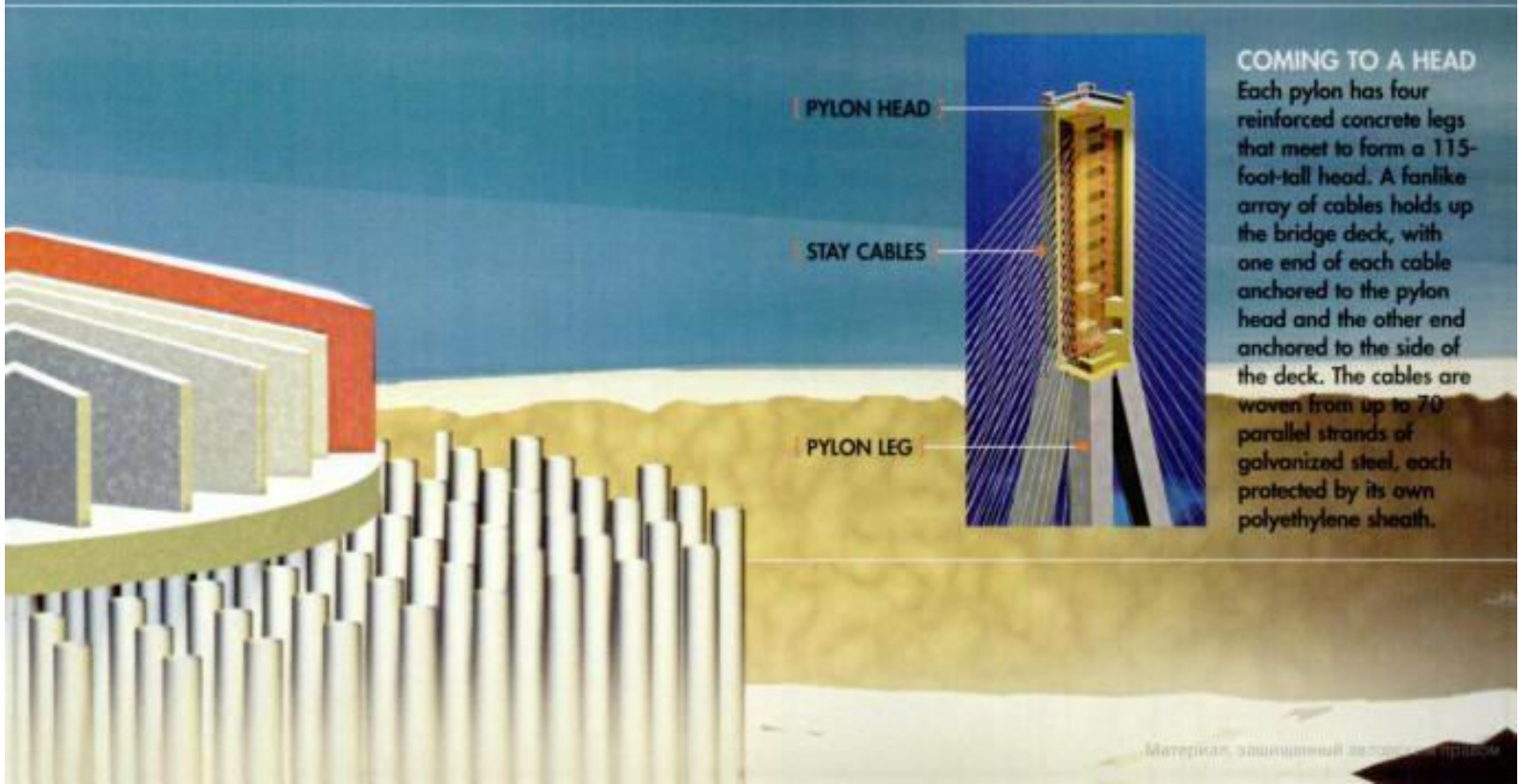
Although the bridge was first proposed more than a century ago, it hasn't been buildable until now. The water is more than 200 feet deep in places, and bedrock lies far beneath the strait's soft soil. Engineers strengthened the soil under the bridge's foundations by studding it with steel "inclusions," giant pipes meant to hold the seabed together during a quake. Indeed, seven earthquakes measuring more than 6 on the Richter scale have struck near the Strait of Corinth in the past 40 years. To further protect against quakes, designers hung the bridge's deck from its pylons like a giant pendulum and added dampers at the base to absorb the jolts of a tremor. Rion-Antirion—also known as the Harilaos Trikoupis Bridge, in honor of the 19th-century Greek prime minister who advocated for it—should withstand winds up to 155 mph, earthquakes measuring up to 7.5 on the Richter scale, and the impact of a 180,000-ton tanker sailing at 18 knots. —DAWN STOVER



BIG FOOT
Probing beneath the sandy seabed, engineers discovered that bedrock lay too deep to anchor the bridge. Their solution: Each of the four piers rests on a broad, hollow foundation known as a caisson. At 295 feet in diameter, they are the broadest ever built for a bridge. To stabilize the weak soil below these massive structures, workers drove hundreds of hollow steel pipes—each more than 80 feet long and 6.5 feet wide—into the seabed and covered them with a layer of gravel.

UNITING NORTH AND SOUTH

The bridge spans the Strait of Corinth, which divides mainland Greece from the Peloponnese peninsula to the south. Before it was completed, travel by ferry across the strait took 45 minutes; now the trip is only five minutes. The bridge's name comes from the two towns on either side of the crossing. Antirion is on the mainland; Rion is on the peninsula.



COMING TO A HEAD

Each pylon has four reinforced concrete legs that meet to form a 115-foot-tall head. A fanlike array of cables holds up the bridge deck, with one end of each cable anchored to the pylon head and the other end anchored to the side of the deck. The cables are woven from up to 70 parallel strands of galvanized steel, each protected by its own polyethylene sheath.

HANGING OUT Because the steel deck below the bridge's concrete roadway is fully suspended, it will sway, not snap, during an earthquake. A strut connected to the pylon base holds the deck in place during high winds, but during a major earthquake, the strut is designed to break. Should that happen, four hydraulic dampers will act like shock absorbers, letting the frame sway to absorb the earthquake's energy.

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POWER POINTS

YEAR BRIDGE WAS FIRST PROPOSED | 1880

YEAR CONSTRUCTION BEGAN | 1998

CONCRETE REQUIRED | 661,500 tons

NUMBER OF STEEL CABLES USED | 368

EXPECTED TRAFFIC, VEHICLES PER DAY | 10,000+

COST OF BRIDGE | 800 million euros ($982 million)

CAR TOLL TO CROSS | 9.70 euros ($12)

STRENGTH IN NUMBERS | How Rion-Antirion stacks up against other record-setters

Rion-Antirion's five spans make it the longest cable-stayed bridge in the world. But bragging rights are often determined by the length of a bridge's main (or central) span rather than its overall length, and there Rion-Antirion falls short. Japan's Akashi-Kaikyo suspension bridge has the world's longest main span, and the country's Tatara Bridge has the longest main span of any cable-stayed bridge. Shown here are four of the world's most spectacular bridges, along with their location, main span and total span lengths.

[AKASHI-KAIKYO Japan]
main span total length
6,532 feet • 12,831 feet

[RION-ANTIRION Greece]
1,837 feet • 7,388 feet

[GOLDEN GATE U.S.]
4,200 feet • 6,450 feet

[TATARA Japan]
2,920 feet • 4,856 feet

INFOGRAPHICS BY MIKA GRONDAHL

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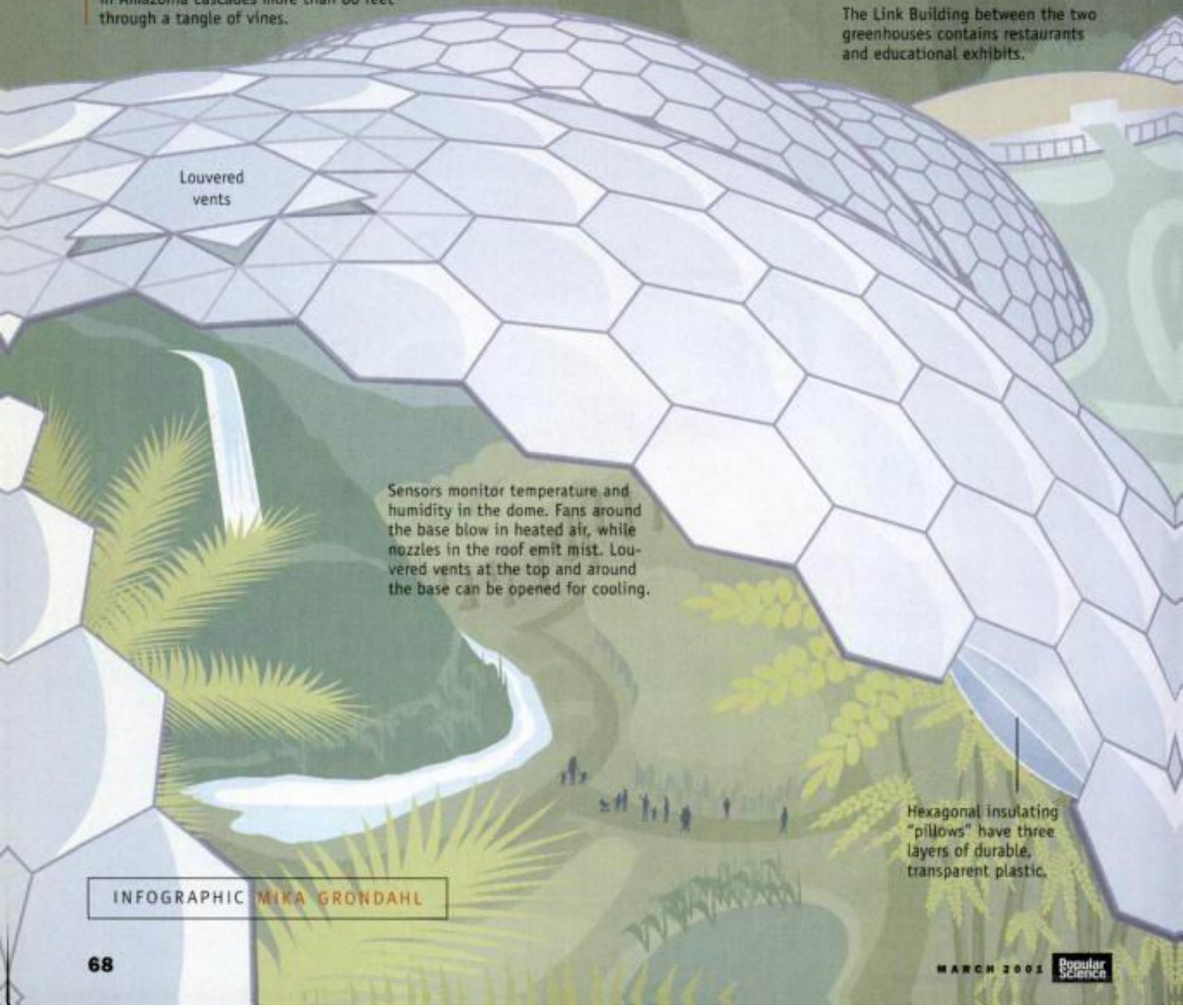
By Dawn Stover

Power Plants

The world's largest greenhouse holds plants that have changed history.

Humid Tropics Biome
The Humid Tropics Biome features plants from the Oceanic Islands, Malaysia, West Africa, and the Amazon. They include coconut palms, mangroves, nutmeg, rice, passion flowers, rubber, coffee, bananas, mangos, balsa, teak, and cocoa. A waterfall in Amazonia cascades more than 80 feet through a tangle of vines.

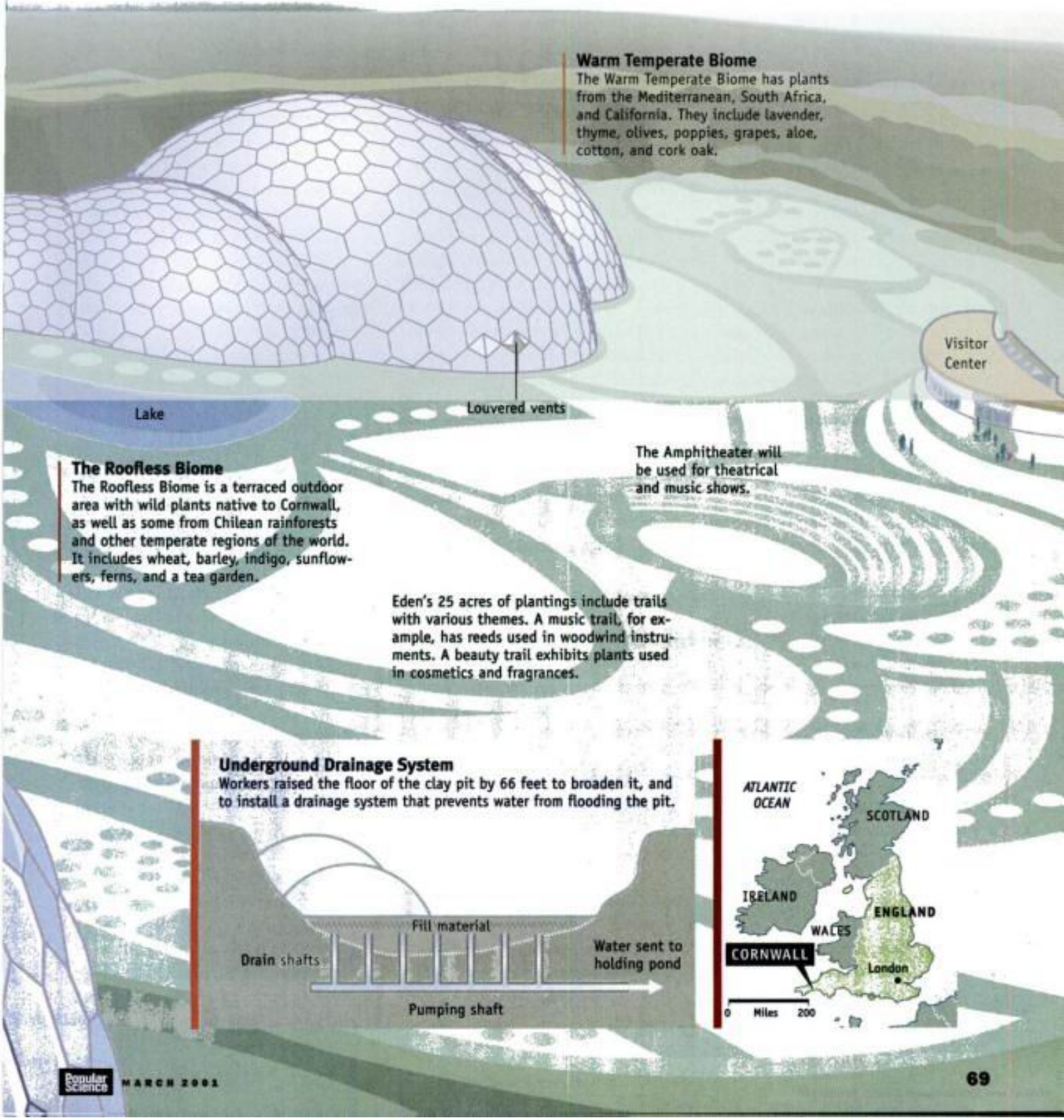


INFOGRAPHIC MIKA GRONDAHL

THE PLANT WITH 1,001 uses has found an unlikely home—a surrealistic edifice rising from an abandoned clay pit in southwest England. There, you can find growing a grass used daily by more than half the world's population. Valuable for skyscraper scaffolding, airplane skins, bicycles, musical instruments, furniture, toys, paper, fuel, food, medicines, and even acupuncture needles, it was used to make the first suspension bridge and the first successful filament for Edison's light bulb. It grows faster than any other plant on Earth, as much as 4 feet in a single day. It's known as "the wood of the poor" in India, "the friend of the people" in China, and "the brother" in Vietnam.

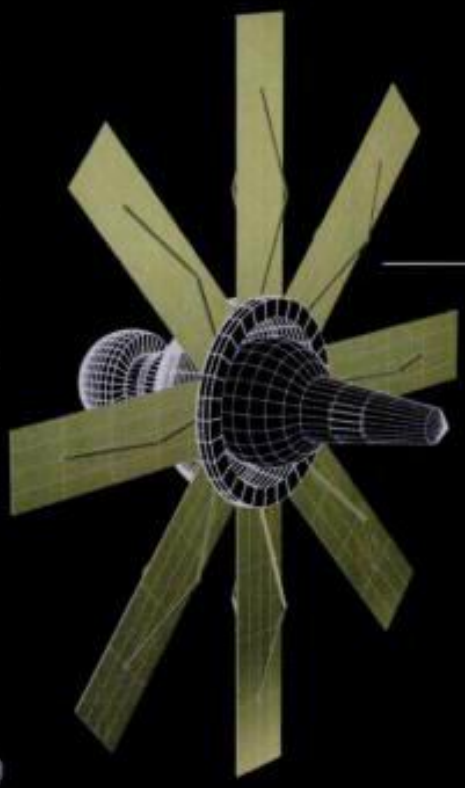
Such trivia about commonplace bamboo finds an enthralled audience at the Eden Project in the Cornwall region of England. "Eden was designed to create a theater," says education manager Jo Readman, "to tell the story of plants that changed the world." Plants such as bananas, over which wars have been fought. Plants such as cotton, inspiration for the industrial revolution and the rationale for slavery on two continents. And plants such as coffee and sugar, among the most heavily traded products in the world today.

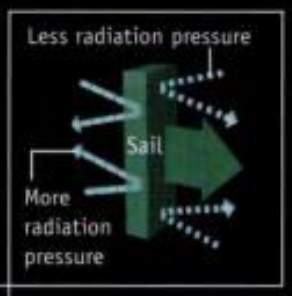
There are 250,000 species of plants on Earth. The Eden Project



SEVEN SPACE DRIVES

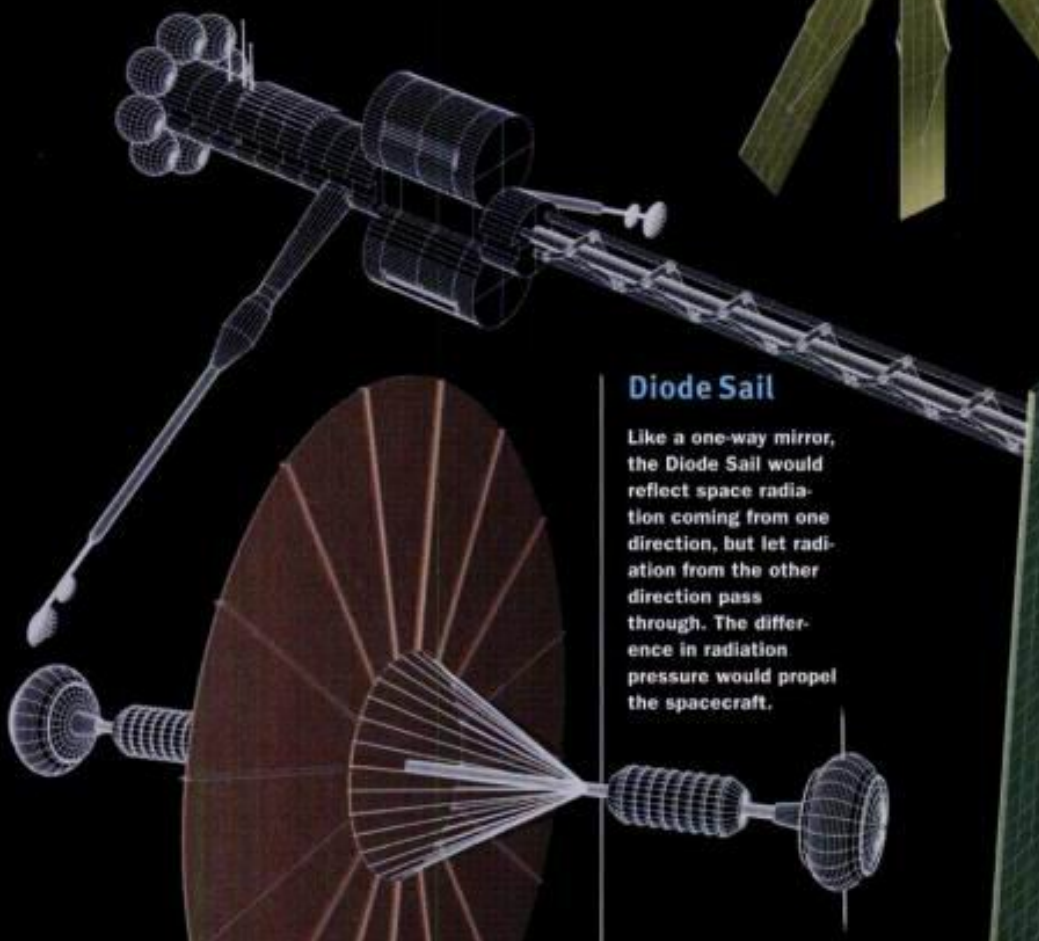
WHILE WORK ON THE ESSENTIAL physics questions is in its earliest stages, that hasn't stopped scientists from thinking about how to harness potential new sources of spacecraft propulsion. Marc Millis of NASA's Glenn Research Center in Cleveland has suggested hypothetical space drives, shown in these POPULAR SCIENCE artist's concepts, to spotlight the problems and possibilities of physics yet to be discovered. While these designs would dramatically reduce or eliminate propellant, they would still be limited to travel close to light speed—except perhaps for the Induction Ring on page 50. If just one of these could be made to work, we'd have a breakthrough. But that is one big If.—*M.D.*





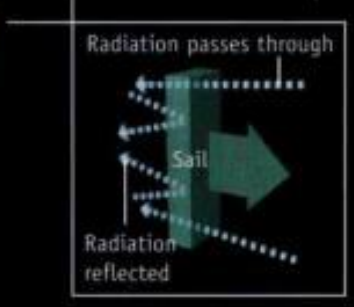
Induction Sail

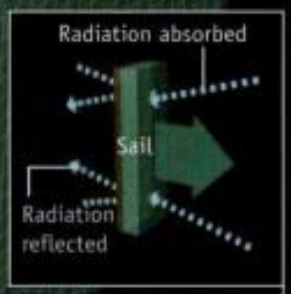
The pressure of radiation on one side of the Induction Sail is increased by some yet undiscovered means, and the pressure on the other side is lowered. The spacecraft moves toward the low-pressure area.



Diode Sail

Like a one-way mirror, the Diode Sail would reflect space radiation coming from one direction, but let radiation from the other direction pass through. The difference in radiation pressure would propel the spacecraft.





Differential Sail

Today's rockets zoom along thanks to collisions between the rockets themselves and their propellant. These collisions push the rocket in one direction and the propellant in the other. A hypothetical collision sail would work the same way. Imagine that space has some form of background radiation that is constantly impinging on the spacecraft—perhaps random particles or electromagnetic waves. If you could absorb the collisions in front of the vehicle and reflect the ones behind it, the spacecraft would be pushed ahead.

20,000 21,000 22,000 23,000 24,000 25,000 26,000

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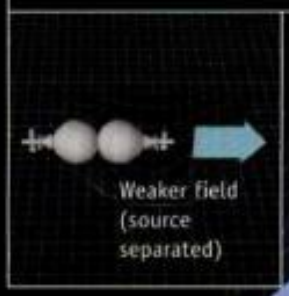
Disjunction Drive

One of the most speculative of speculative space drives. The name disjunction refers to the idea of separating the source of a field from that which reacts to the field (normally considered inseparable), resulting in forces on the part that normally reacts to the field.

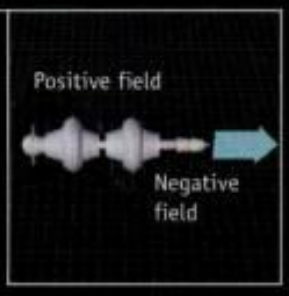


Induction Ring

An induction ring of negative energy—analogous to negative numbers—would warp space into a sort of bubble around the spacecraft (similar to the effect created by the Bias Drive, below).

Diametric Drive

Today, scientists know that interactions between matter and fields produce force. For instance, gravitational fields accelerate masses—like the apple that supposedly struck Newton. And electric fields accelerate charges. If a spacecraft could create an asymmetric field around itself somehow, then perhaps the field would propel the spacecraft. The Diametric Drive, a generic version of a 1957 "negative mass propulsion" concept, uses the interactions of a positive and negative field to propel the spacecraft.



Bias Drive

The Bias Drive would alter the properties of space itself. For instance, it could reduce normal gravity on one side to produce thrust. Imagine a boat made from a block of wood with one pointed end and the other end indented. The block is floating on water, and you drop detergent behind it. Because soap changes the surface tension of the water, the boat is pushed along.

28,000 29,000 30,000 31,000 32,000 33,000 34,00

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YOU'RE THE MASTER; THIS IS YOUR UNIVERSE

TOMORROW'S SMART GARAGE IS READY TO OBEY YOUR EVERY WHIM.

The garage of the future will still shelter your car and serve as a place to store your lawn mower and other indoor-outdoor equipment. But according to visionaries we interviewed at organizations ranging from the Ultimate Garage to the Electric Power Research Institute, in 10 years your garage will also be a savvy service center. Multiple power systems will ensure that your house consumes—and generates—energy as efficiently and inexpensively as possible. A team of robots will automatically take out the trash, accept and sort deliveries and trim your lawn—but only if it needs it. And sensors will valet park your vehicles and keep tabs on their condition. All you'll have to do is sit back and enjoy the ride.—CHARLES WARDELL

CAR TECH **Pull up to your garage, press the park button, and infrared beams help your car guide itself into the bay correctly [1]. Once parked, your car transmits data wirelessly to a diagnostic station in the garage [2]. The system's display tells you when it's time for regular maintenance—like a 300,000-mile tune-up—and warns you if something needs attention, presenting all your options. If you're handy, use the touchscreen [3] to display your car's manual, and order parts if necessary; it will then walk you through the repair. If you'd rather not sully your mitts, beam the diagnosis to your repair shop for an estimate. The mechanics can use their own computers to do a more in-depth remote diagnosis and notify you if and when you need to bring it in. A handheld camera lets you send visual as well as electronic information.**

SMART STORAGE **Shelves [4] have built-in scales to keep track of how much fertilizer, grass seed and other lawn-care products you've used. They automatically scan Radio Frequency Identification (RFID) tags in product labels as items are removed and replaced, and update the inventory on your home computer. An RFID label maker [5] lets you inventory the contents of your own storage boxes so you know exactly where you stashed the holiday decorations. To maximize storage space, all these boxes, as well as bikes, boats and other recreational toys, are stored on the second story with the help of an electric lift [6].**

HOME POWER SYSTEM **Your home will still be connected to the grid, but it will also include two of its own power-generating systems: a photovoltaic roof array [7] that can deliver energy directly to your home and a hydrogen fuel cell [8]. A central controller [9] coordinates these systems. When the sun is shining and you need power, the solar rooftop system supplies it. If it's a blue-sky day and nobody's home, the solar energy powers a reformer, which extracts hydrogen from water; the hydrogen is stored safely in a subterranean tank [10]. As a last resort, if it's cloudy *and* your fuel cell's out of hydrogen, the controller finds out through the Internet which utility has the lowest rates at that instant, and draws from the grid.**

YARD CARE **The irrigation system [11] goes online to check National Weather Service reports and municipal water restrictions, using the information to decide when to water. A small army of robotic lawn maintenance tools can make decisions based on the same data, and automatically groom your yard accordingly. You'll have single-function bots like a yard vacuum [12]**

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7 PHOTOVOLTAIC ROOF ARRAY

ELECTRIC LIFT 6

SMART SHELVES 4

1 PARKING SENSOR

TRASH BOT 15

DOOR BOT

12 YARD VACUUM

10 HYDROGEN TANK

and edger [13], as well as a mower that takes attachments such as an aerator [14]. The bots rest on their charging stations between jobs.

TRASH BOT A robotic trash can [15] sits on a charging station by the back door to the house. It has an automated routine to wheel itself to the curb on collection night.

(HOUSE OF THE FUTURE CONTINUED ON PAGE 22) ►

POPSCI CONCEPT

DOOR BOT Think of the door bot as a robotic gopher. It stashes packages from the delivery guy. Once he keys in a one-time code and leaves your packages in a double-secure storage bay, the bot scans the embedded RFID tags and automatically puts the boxes on the correct shelf or in the fridge (or freezer). It finds and retrieves items for you from the second-floor storage room. And it fetches and puts away your tools.

INFOGRAPHIC BY KENN BROWN AND CHRIS WREN

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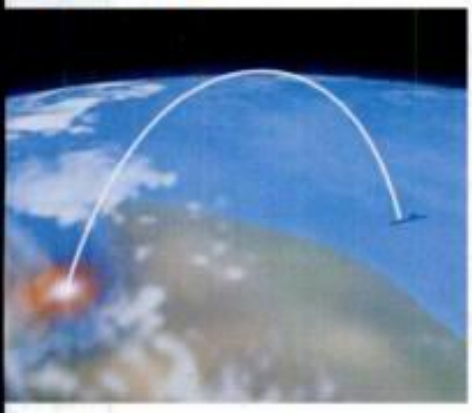
#1

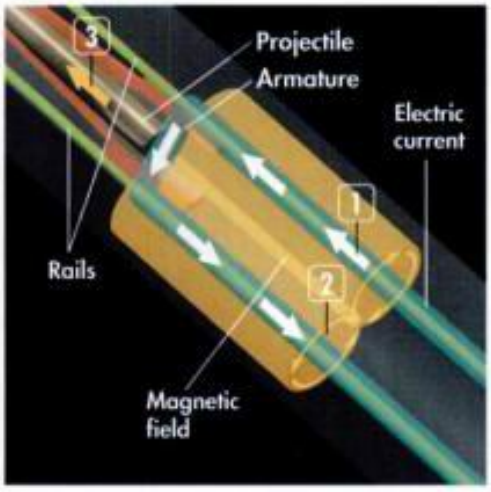
ELECTRO-MAGNETIC RAILGUN

Projectiles fired from an electromagnetic railgun will travel up to 290 miles in less than six minutes, exiting the atmosphere before hurling into their target at a velocity of 5,000 feet per second. The force of the impact will obliterate targets without an explosive aid.



#1 A KINETIC MISSILE THAT FLIES AT MACH 7

Picture this: A massive destroyer receives the location coordinates of an enemy headquarters more than 200 miles away. Instead of launching a million-dollar Tomahawk cruise missile, it points a gun barrel in the direction of the target, diverts electric power from the ship's engine to the gun turret, and launches a 3-foot-long, 40-pound projectile up a set of superconducting rails. The projectile leaves the barrel at hypersonic velocity—Mach 7-plus—exits the Earth's atmosphere, re-enters under satellite guidance, and lands on the building less than six minutes later; its incredible velocity vaporizes the target with kinetic energy alone.



A railgun uses electric current to launch a projectile. The current—up to 15 million amps—travels up one rail and down the second (**1**). This current induces a magnetic field across an armature (**2**) that bridges the rails. This armature also carries a current; the interaction between this current and the magnetic field accelerates the armature, and the projectile aboard it, to Mach 7 (**3**). Adjusting the range of the weapon is as easy as reducing the electric current supplied to the rails—the lower the current, the slower the projectile leaves the barrel and the shorter the distance it travels.

The U.S. Navy is developing an electromagnetic railgun that will turn destroyers into super-long-range machine guns—able to fire up to a dozen relatively inexpensive projectiles every minute. The Navy is collaborating with the British Ministry of Defence, which has a similar effort under way. In 2003, its facility in Kirkcudbright, Scotland, hosted a ⅓-scale test of an electromagnetic railgun that produced stable flight in a projectile fired out of the barrel at Mach 6. But Capt. Roger McGinnis, program manager for directed energy weapons at Naval Sea Systems Command in Washington, D.C., estimates the U.S. version won't be "deliverable" until 2015 at the earliest.

The technology behind the electromagnetic railgun has been around for more than 20 years, but early efforts wilted because of the huge power requirements: No ship could generate or store enough electricity to fire the gun. The concept was revived a few years ago when the Navy announced plans for its next-generation battleship, the all-electric DD(X). "In the past, destroyers had 90 percent of their power tied to propulsion," explains McGinnis. "But with DD(X), you can divert the power to whatever you need. We can stop the ship and fire the railgun as many times as we need, then divert the power back to the screws."

The barrel of the electromagnetic railgun will contain two parallel conducting rails about 20 feet long, bridged by a slid-

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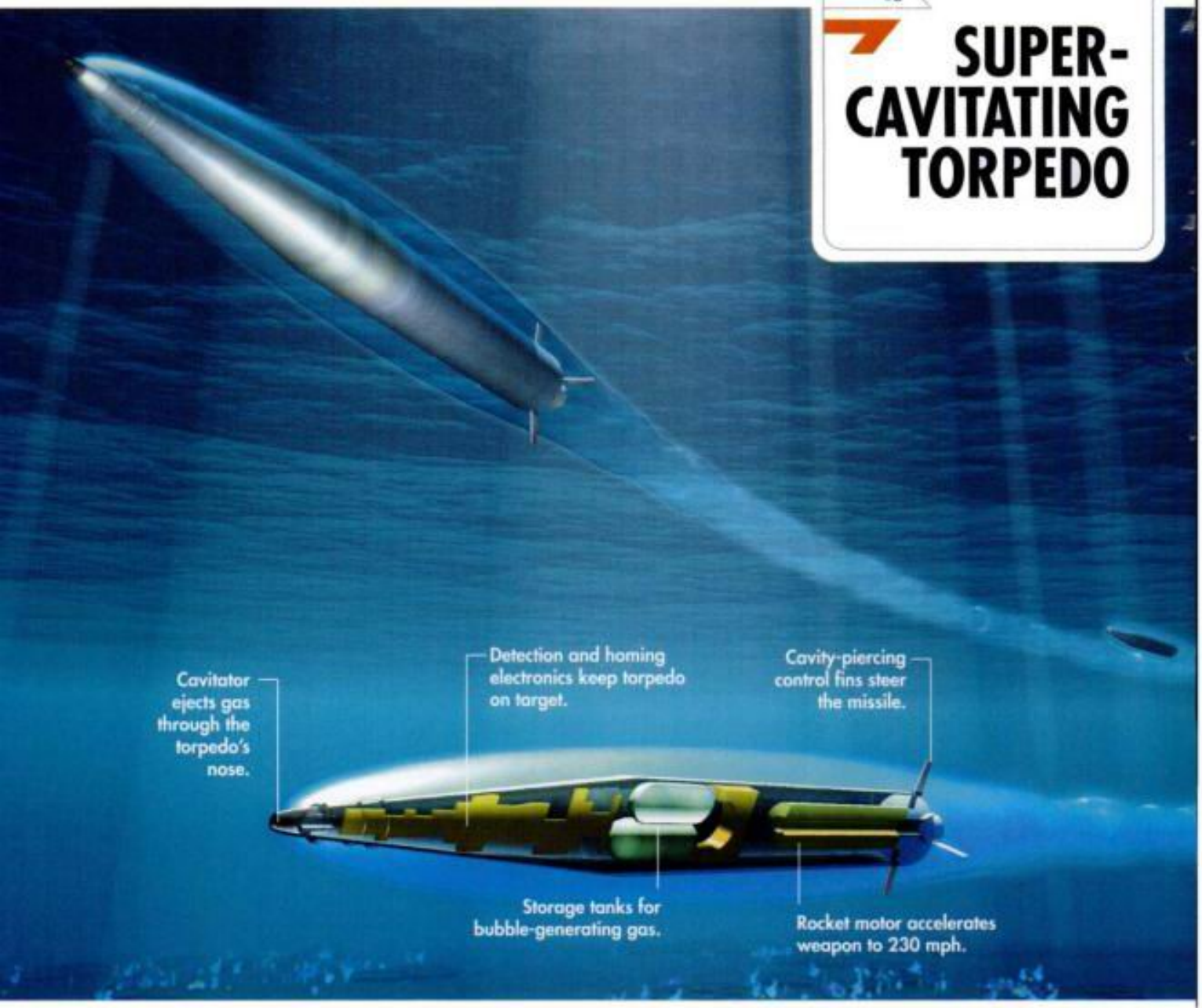
#2

SUPER-CAVITATING TORPEDO



Several challenges remain for the supercavitating torpedo, including how it will be steered underwater. Water-tunnel tests have already proven that speed can be achieved: In 1997, the Navy tested a supercavitating projectile that reached 5,082 feet per second, becoming the first underwater projectile to exceed Mach 1.

ing armature. In the current design, electric current travels up one rail, crosses the armature, and heads down the second rail. The loop induces a magnetic field that pushes the armature, and the projectile aboard it, up the rails.

The challenges that remain include ensuring that the gun can target enemy sites with precision, and creating equipment that can withstand the gargantuan pressures the gun will create. "Right now, guns are only as accurate as the targeting of the bore, and now we're talking about 200-plus-mile ranges, so there has to be aerodynamic correction," says Fred Beach, the assistant program manager for the electromagnetic railgun at Naval Sea Systems Command. The projectile, he says, will receive course correction information from satellites and will steer itself with movable control surfaces. And because the projectile will be subjected to up to 45,000 Gs during firing, the onboard electronics must be strengthened to withstand the acceleration. Forces inside the gun itself—particularly getting the armature to move easily within the system—are also challenging the designers. "Getting two pieces of metal to slide past each other is pretty hard—we're getting a lot of damage to the rails," Beach says.

The electromagnetic railgun's projectiles will cover 290 miles in six minutes—initially traveling 8,200 feet per second and hitting their target at 5,000 feet per second. Current Navy guns, which shoot powder-ignited explosive shells, have a maximum range of 12 miles and, because they are unguided, are difficult to aim. Though guided missiles, the current long-range alternative for destroyers, can achieve ranges comparable to that of the electromagnetic railgun, their cost and storage problems are what's driving the efforts to find an alternative. Ships can only carry up to 70 guided missiles and must return to port to restock because the missiles cannot be loaded at sea, whereas railgun projectiles can easily be loaded at sea, and by the hundreds. Also appealing is that the electromagnetic railgun's missiles do not contain volatile explosives; the weapon does its work with kinetic energy.

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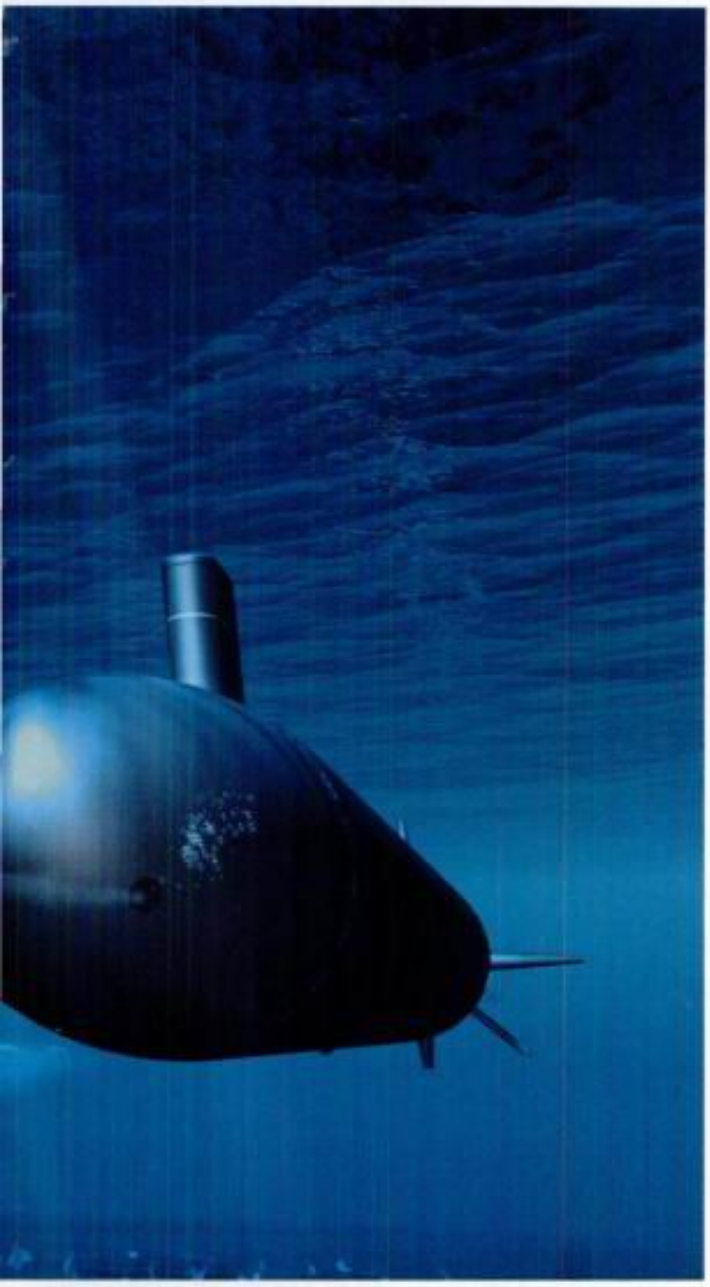

#2 A ROCKET TORPEDO THAT SWIMS IN AN AIR BUBBLE

Submarines peaked in power and relevance during the Cold War; there has since been a shift in focus to aircraft-based combat, and subs have become budget-cut victims. But subs are still prized for their ability to sneak about global waters undetected and to defend surface ships from attack. Many U.S. subs are being converted from missile launchers into delivery vehicles for special operations troops.

But the supercavitating torpedo—a rocket-propelled weapon that speeds through the water enveloped in a nearly frictionless air bubble—may render obsolete the old submarine strategy of sly maneuvering and silent running to evade the enemy. The superfast torpedo could be outfitted with conventional explosive warheads, nuclear tips or nothing at all—a 5,000-pound, 230-mph missile could do enough damage on its own. The Russians invented the concept during the Cold War, and their version of this underwater killer—dubbed the Shkval ("Squall")—has recently been made available on the international weapons market; the United States, of course, wants a new, improved version of the original.

The hard part about building a rocket-propelled torpedo isn't so much the propulsion as clearing a path through the ocean. Water creates speed-sapping drag; the best way to overcome that drag is to create a bubble that envelops the torpedo—a supercavity. A gas ejected uniformly and with enough force through a cavitator in the nose of the torpedo will provide such a bubble, permitting speeds of more than 200 mph and a range of up to 5 miles (traditional torpedoes have slightly longer ranges, but lumber at only 30 to 40 mph).

Though submerged, the torpedo remains essentially dry, with a frictionless surface. "That sounds easy, but doing it is extremely difficult, especially if you're trying to steer," says Kam Ng, program manager for the torpedo at the Office of Naval Research, which has been developing the weapon since 1997. "If your torpedo moves in a straight line, you just aim and shoot," says Ng. "That capability already exists with Shkval. But the U.S. vehicle will be more capable—it will turn, identify objects, and home in on the target." (Improvements to the torpedo to make it steerable likely froze when the Soviet Union collapsed, says GlobalSecurity.org's Pike.)

Among the greatest challenges for U.S. torpedo researchers is developing detection and homing technology that will enable the torpedo to distinguish an enemy sub from, say, a rock formation, says Ng. Also tricky is finding a way to control the gas bubble to permit those course changes. "When you turn, the bubble distorts because it is no longer symmetrical," he says. "So you have to compensate for that by putting more bubble to one side." This is done, Ng explains, by ejecting more gas toward the outside of the turn.

Naval officials say the high-speed torpedo will enable submarines to attack enemy subs and surface ships without giving them time to respond. The U.S. military has tested a prototype, but combat-ready versions are not expected for at least 15 years.

#3 A LASER CANNON THAT BLASTS FROM THE AIR

Directed-energy weapon specialists at the Air Force Research Laboratory are close to overcoming the two main hurdles that have confined laser weapons to science fiction for the last half-century. Tests by lead contractor Boeing have demonstrated that the laser has enough power to function as a weapon, and that the chemical exhaust, which could pose a considerable threat to the weapon's operators and individuals on the ground, can be safely contained in a sealed system. If all goes according to the U.S. Special Operations Command's plan, within a decade or so the Advanced Tactical Laser may introduce a new class of weaponry to the battlefield.

The weapon's first incarnation, expected by 2010 at the earliest, will be a megawatt-class chemical oxygen-iodine laser (COIL) fired from a rotating turret beneath the nose of a C-130 gunship. The beam could be up to 4 inches in diameter and have a 20-mile range—enabling it to burn through vehicles and machinery with a precision and millisecond timing that missiles and cannons can't achieve. (Cannons, in particular—now centuries old in concept—are tricky to aim. These "indirect fire" weapons must be pointed far from the target to factor in wind speed, humidity, firing force—even the rotation of the Earth.)

Next on the agenda: developing targeting, tracking and firing

Watch Metal Storm in action at **popsci.com/exclusive**

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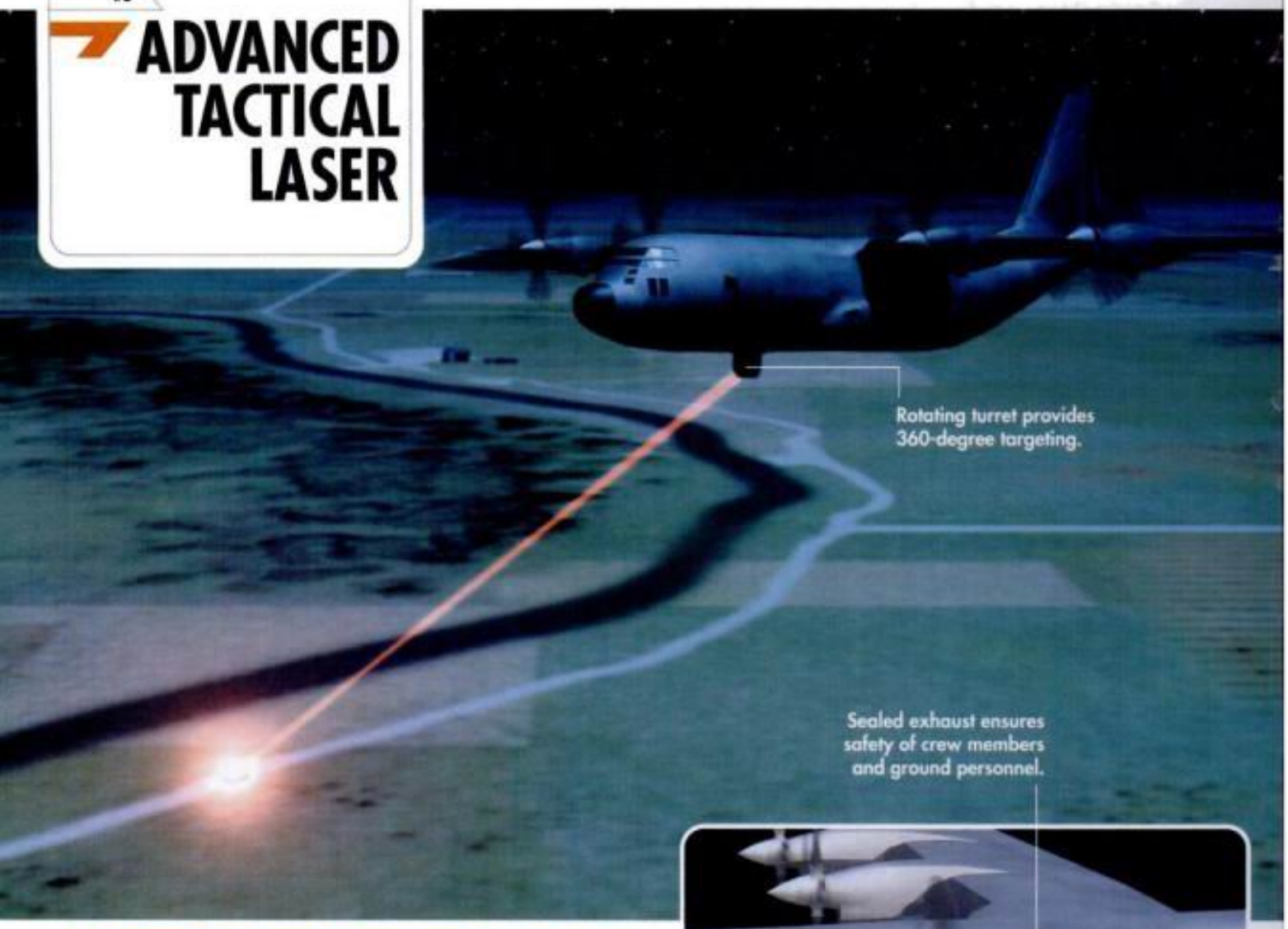
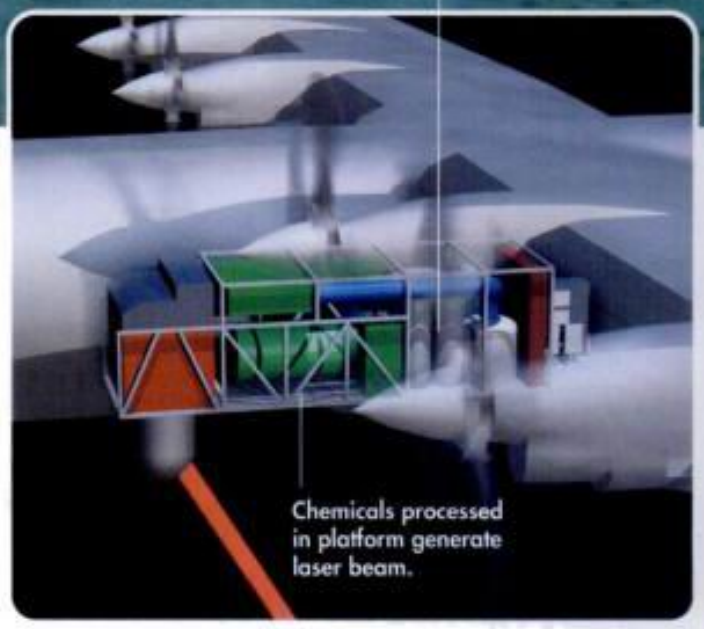
#3

ADVANCED TACTICAL LASER





The Advanced Tactical Laser, fired from a Special Forces A/C-130 Gunship, will have a range of up to 20 miles, as well as pinpoint accuracy and speed-of-light responsiveness. The first generation will employ chemical lasers, which will later be replaced by diode-pumped solid-state lasers powered by electricity.

hardware. Among the questions researchers must answer: how long must the beam linger on a target to have the desired effect. "There are some interesting things with the directed energy technologies that we just don't know about," says Lt. Col. Joseph Panetta Jr., program manager for the Advanced Tactical Laser at the U.S. Special Operations Command headquarters at MacDill Air Force Base in Florida. "We need to determine exactly how it will perform on the battlefield."

Laser weapons are a relative bargain compared with existing long-range weapons: They're expected to cost $8,000 per shot versus up to hundreds of thousands for missiles. Lasers are also tunable, which adds versatility: When less-than-lethal force is required, such as in urban areas or when hostages are present, the beam's duration can be reduced so that it disables technology but only injures people. "We want a system that can generate a variety of effects on the battlefield, from damaging something to totally destroying it, to just kind of harassing with it," Panetta says. "This seems to offer us that."

Next-gen tactical lasers will likely be electrically-powered and diode-pumped, since chemical lasers require storage and transport of heavy ingredients. The greatest challenge with electric lasers, says Lt. Col. JoAnn Erno, head of the power division at the Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio, is managing the heat that's generated—lasers are only 10 percent efficient, so 90 percent of the power is lost in heat. "Controlling the heat will require active cooling," she says, "such as spraying the laser's diodes to keep them from overheating." Solid-state lasers will be smaller than chemical ones, permitting their use on fighter jets and ground vehicles. The Joint Strike Fighter, due to enter service in 2009, is a well-suited potential platform, says Erno, because its engine includes a metal shaft that spins fast enough to easily power a laser.

Lasers are an example of a weapon that should be developed

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The flier's ducted-fan-laden wings tilt to hover, steer, and even fly backward.
The bottoms of the crawler's "toes" are covered in minuscule fibers, allowing them to climb smooth surfaces much the way a gecko does.

No. 5

ROBOTICS

Robot Bugs: Handy, Not Icky

>> Equipped with "inchworm" motors and sonar, and built with MEMS processes, tiny inspecto-bots will scurry and fly, performing investigations for their human controllers.

Video cameras mounted on the spider bot's head check electrical or fiber-optic wiring for frayed insulation, or structural beams for termite damage.

Bugs can go places that humans can't; they cooperate better than almost any other organism; some of them can even fly. It's those desirable traits that are driving robotics toward a future that looks more like *A Bug's Life* than *The Jetsons*.

Within a decade or so, swarms of mechatronic bugs outfitted with sensors and wireless transceivers will likely be burrowing through the rubble of buildings to search for earthquake survivors and scrabbling over the hull of a spacecraft to repair damage inflight. They'll also be the home inspector's trustiest tool. Imagine the bots scurrying into a house's plumbing looking for leaks, boring into the insulation in search of asbestos, or checking out that sketchy crawl space.

Professor Kristofer Pister of UC Berkeley's Center for Information Technology Research in the Interest of Society (CITRIS) and graduate student Sarah Bergbreiter are making progress in that direction. The researchers recently fabricated a solar-powered microrobot just 0.33 inches long and less than 0.16 inches wide.

"I've had this dream of making silicon walk," says Pister, inventor of Smart Dust, tiny wireless sensors with myriad applications—from diagnosing a building's structural integrity to monitoring sensitive ecosystems. Pister's plan is to give Smart Dust legs.

Key to his microrobot's locomotion will be novel "inchworm" motors that work by repeatedly engaging and releasing a shuttle that pulls a leg forward a minuscule amount. Right now, his bot has just two limbs, which aren't quite strong enough to drag along its body. Still, the bug demonstrates that tiny autonomous robots can be fabricated with MEMS (micro-electromechanical systems) processes, similar to the way integrated circuits are manufactured.

More advanced but bulkier are the matchbox-size millibots built by engineering professor Pradeep Khosla of Carnegie Mellon University and his grad students Robert Grabowski and Luis Navarro-Serment. Their latest battery-powered millibots were constructed using off-the-shelf components and employ a combination of ultrasonic sensing and sonar to navigate uncharted territory.

Meanwhile, researchers at UC Berkeley, Seiko Epson Corporation and other laboratories hope to unleash flocks of winged microrobots. Most recently, Seiko Epson applied the design lessons learned from its Monsieur microrobot to a helicopter-like robot levitated by contra-rotating propellers. The one-third-ounce, 5-inch-diameter μFR (Micro Flying Robot) sports a tiny ultrasonic motor for propulsion and a linear actuator for stabilization. A low-power Bluetooth module will enable wireless control at distances up to 30 feet.

When a robotic fly designed by CITRIS researcher Ronald Fearing takes off, it will draw power from a 30mW lithium-ion battery on its rear. The robot is smaller than a quarter and weighs in at just 0.0035 of an ounce. A wee piezoelectric motor causes its single wing to simultaneously flap and rotate 150 times per second. The goal, Fearing says, is to outfit the fly with a tiny video camera and Smart Dust sensors for search-and-rescue and reconnaissance missions.

Whether the next generation of robots scurry along the ground or take to the air, they'll be essentially simple creatures. "The more capability you integrate into a single system," Khosla says, "the higher the probability of failure."—DAVID PESCOVITZ

ARTHROPODA: INSPECTA

CRAWLER BOT
GOOD FOR: Examining the interior of ducts or pipes.

SPIDER BOT
GOOD FOR: Inspecting wires and cables.

FLYING BOT
GOOD FOR: General surveying; building exteriors.

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space shuttle. There is some confusion in this, since not one of the specifications of the Orbital Space Plane as currently envisioned could match the shuttle's capacity for crew support, nor its sheer power as a high-tonnage launch system.

To be sure, the OSP's requirements have descended directly from aspects of the three major initiatives mentioned above. But the OSP inherited just three components—for crew return, crew transfer, crew rescue—from complex systems that included launch platforms, light- and heavy-lift capabilities, vehicles for science payloads, cargo and exploration support, as well as the more ordinary, everyday support features for the ISS and its crew.

The inherited crew-transfer component had originally been conceived as one element of a broad, upgradable, long-term system, capable of carrying up to 10 passengers for full-up missions, and of active docking and orbital operations. As the OSP emerged last spring, it had fewer and fewer of those characteristics, until it became the pint-size version of a passive-crew-rescue vehicle envisioned today. A competition that was already under way—and from which several potential bidders had been eliminated—had been radically rescoped to meet immediate political goals within soaring budgetary shortfalls.

Why? Probably because there wasn't enough vision or commitment behind the shuttle-replacement plans to begin with.

What should have happened? NASA should have continued to develop the architecture for a true shuttle-replacement system and requested that the crew-transfer part of the program be fast-tracked; or, if that approach didn't seem responsive enough to the needs of the day, the table should have been swept clean and the process started afresh with a new set of problems on the boards.

One result of the retrofitting rush that gave us the OSP initiative is that the smaller, more risk-taking and often more dynamic companies were knocked out of the bidding before it even got going. Now that the OSP only need accommodate four people and ride atop an expendable, commercial launcher, it's beginning to look to me an awful lot like the various vehicles being developed by the contenders for the X Prize. Yet by the nature of the bidding, none of those 25 teams has any chance of bringing its space-plane concepts to OSP. What would be the result if NASA were to enable this sharing of ideas by inviting competition and reopening the field of design solutions? Most likely cost savings and superior design.

Here is the recent history of shuttle-replacement systems in a nutshell: Propose and study a succession of systems, then fight to keep a single subcomponent going when the budget is slashed—without considering its long-term compatibility with the rest of the human spaceflight program. All these separate pieces somehow need to be made to fit the next wave of big-picture plans. And the Big Plan bogey keeps shifting—it's anyone's guess how the OSP will fit into the Bush Administration's new space initiative. When the components' utility in a new scenario is hard to prove, they get shot down—no matter how much effort has already gone into their development. They become ideas that go back on the shelf, only to get reinvented by future generations.

More TransHab redesign sketches at **popsci.com/exclusive**

1 PRE-EXISTING DESIGN

A group of structural engineers had drawn up the initial designs before the architects got involved. There was no up or down in these plans—astronauts in different areas would be inverted relative to one another. Besides being disorienting for the crew, this design also constituted an inefficient use of the total volume.

ADAMS:
"It was clear that the horizontal variation really wasn't going to do it. They were having a hard time even drawing a picture that showed both sides, where one person would be upright and the other would be upside down. If you can't imagine it, don't design it."

Crew Support Quadrant

2 ADAMS'S CRITIQUE

Adams first worked to improve the original proposals, rearranging certain elements to suit the crew. Here, she shows two potential seating arrangements meant to enhance socialization. Even these layouts, however, would be too cramped and awkward.

ADAMS:
"When you're buying a family home, you don't want one where the dining room is only four feet wide."

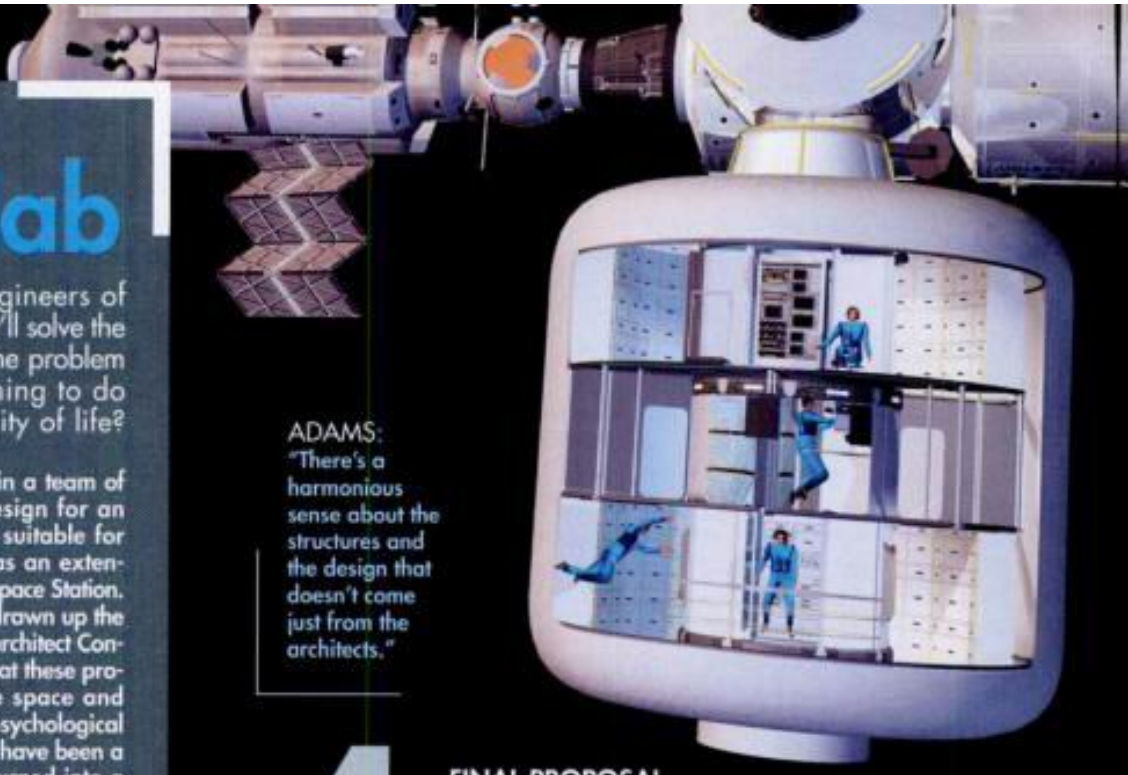
CLOCKWISE FROM TOP RIGHT: BOB SAUIS/FRASSANITO & ASSOCIATES; COURTESY NASA (3)

A CASE STUDY

TransHab

Give the crackerjack engineers of NASA a problem and they'll solve the hell out of it. But what if the problem they're solving has nothing to do with the astronauts' quality of life?

In June 1997 NASA brought in a team of architects to work on the design for an inflatable habitation module suitable for long-duration spaceflight or as an extension node on the International Space Station. NASA engineers had already drawn up the initial plans for TransHab, but architect Constance Adams demonstrated that these proposals made poor use of the space and would likely have a negative psychological effect on the crew. What could have been a devastating clash of cultures turned into a smooth marriage: The architects respected the engineering constraints, and the engineers began considering the critical human factors. In the end, the collaboration led to an ingenious space module and a model for future projects. —GREGORY MONE



ADAMS: "There's a harmonious sense about the structures and the design that doesn't come just from the architects."

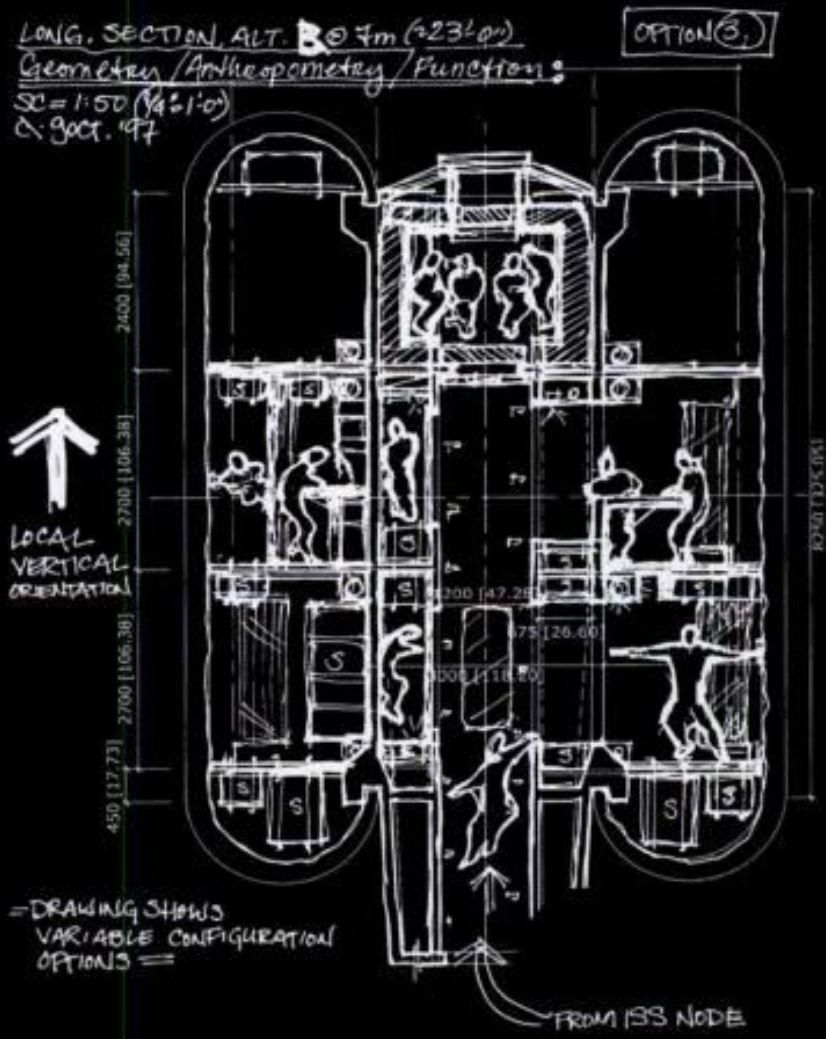
4 FINAL PROPOSAL

The final design incorporated the changes suggested by the architects—the astronauts can move, work, exercise, sleep, and socialize freely—while also adhering to the engineering requirements. Adams contends that the final product was a success because each team internalized the guiding principles of the other.

3 REDESIGN: ROOM TO MOVE AND BREATHE

Adams factored in the two possible roles for TransHab: as a long-duration spacecraft and as an ISS extension node. She included a central core in which crew would travel to and from the ISS, a radiation shelter surrounded by potable water for a Mars flight, social and meeting rooms, vertical sleeping quarters, and enough space within the rooms for astronauts to stretch out their arms. Another of Adams's goals was to design a space that could house a total of 12 astronauts—six ISS and six Mars-bound crew—for the pre-mission periods when TransHab is docked.

ADAMS: "What are these guys going to need to do during their six-month trip to Mars? With a horizontal scheme, you couldn't draw all these people doing all these things. Here, every single cubic meter of the volume is being utilized."



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"AROUND THE WORLD IN 80 HOURS." The happy marketing slogan affixed to Steve Fossett's attempt to set a nonstop, around-the-world solo flight record makes it sound like something of a nostalgic lark: Hints of Jules Verne, the golden age of global adventure. And indeed, if all goes well, sometime later this year Fossett will complete a circumnavigation of the globe, pass over America's Pacific shore, point his wide, spindly airplane—called the Virgin Atlantic *GlobalFlyer*—over the Rocky Mountains, and line up on the same Midwestern runway he left 21,000 miles and 80 hours before. Awake for essentially the entire flight, he will have been battered by turbulence and the mental strain of relentless engine monitoring, fuel management, weather analysis and navigation—to say nothing of actual flying.

That's if things go well. If things do not go well, Fossett's flight will end in a horrific fireball during the incredibly dangerous takeoff of the fuel-pregnant, exquisitely stressed aircraft. Or his distinctly sci-fi-looking airplane—it has a trimaran-like configuration with a single jet engine poised inches above the cockpit's tiny bubble canopy—will disintegrate in turbulence or high-G emergency maneuvering. Or Fossett, despite experience and training, will simply fall asleep. "If he becomes incapacitated—if he falls asleep and doesn't wake up—there will be an accident," says Burt Rutan, the famed aerospace designer who created *GlobalFlyer*. "There's no autoland capability and no way of controlling the airplane from outside the cockpit."

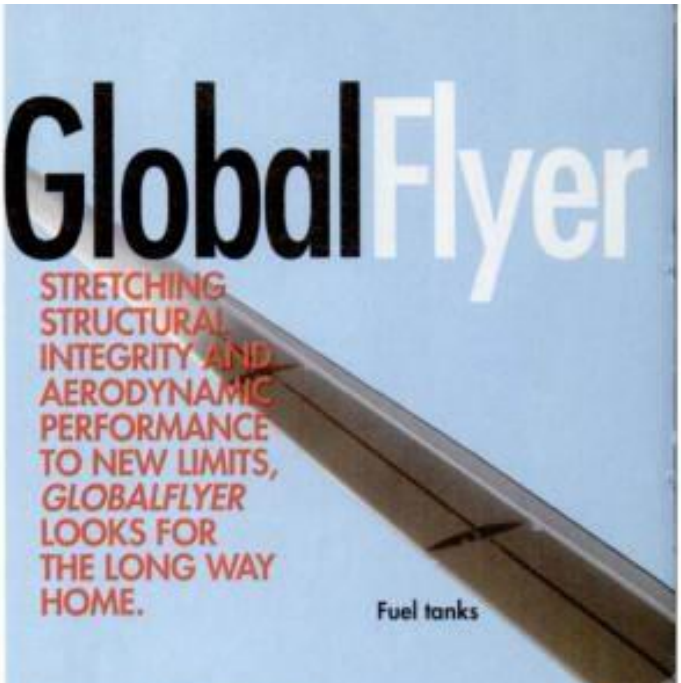
Burt Rutan

This is, in other words, a delightfully dangerous undertaking. The airplane is a flying fuel tank that must remain controllable in buffeting winds at high altitude while it burns through 82 percent of its weight. But Fossett is confident. For starters, the 59-year-old businessman, who made his fortune as an investment banker and his fame as an adventurer, has done this kind of thing before. His nautical and aviation records include the first nonstop solo flight around the world in a balloon, which he achieved in 2002 on his sixth try. (He is also currently shooting for a glider altitude record of 62,000 feet, and on Nov 14 in Argentina set a glider distance record of 1,244 miles.) His partner in adventure, Sir Richard Branson, the swashbuckling founder, CEO and chairman of project-sponsor Virgin Atlantic, is an old ballooning buddy with world records of his own—and will serve as Fossett's reserve pilot. And Fossett can place a lot of faith in his aircraft and the man who designed it: After all, Burt Rutan built the historic, prop-driven *Voyager* airplane, which his brother, Dick Rutan, and Jeana Yeager flew on a nine-day around-the-world unrefueled flight in 1986.

THE TECHNOLOGY. *GlobalFlyer* represents a bigger technical challenge than even *Voyager* did. The latter airplane, which now hangs in the Smithsonian's National Air and Space Museum, flew with two piston engines, carried 7,000 pounds of fuel, and had two pilots. *GlobalFlyer* will sprint where *Voyager* strolled, and its design pushes weight-reduction and structural-integrity technology to the absolute limits. (The fuel tanks in the twin outboard booms are informally referred to as watermelons—not the most reassuring analogy.) With

GlobalFlyer

STRETCHING STRUCTURAL INTEGRITY AND AERODYNAMIC PERFORMANCE TO NEW LIMITS, *GLOBALFLYER* LOOKS FOR THE LONG WAY HOME.



CONTROL SYSTEMS

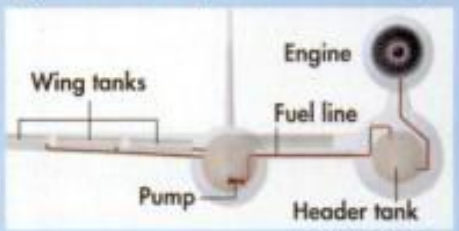
The high-tech instrument panel includes a touchscreen display, GPS nav, live satellite-fed weather and autopilot; the old-fashioned flight controls still use cables and pushrods.

80 HOURS OF COMFORT

The carbon-fiber seat can be upright or reclined. For takeoff and landing, the pilot sits on cushions to see out the canopy; he'll use instruments to navigate at other times.

A FLYING GAS TANK

Sixteen fuel tanks inside the plane's wings feed fuel into the header tank beneath the engine. The tanks require constant monitoring to maintain the plane's balance in flight.



FROM LEFT: JOHN B. CARNETT; JOHN MACNEILL

GLOBALFLYER VS. VOYAGER

GlobalFlyer might go nonstop around the world, a feat Voyager accomplished in 1986. But that's where the similarities end. With new aerodynamics, materials and design, Burt Rutan's new craft is significantly more sophisticated than the old record breaker.

AERODYNAMICS: The *GlobalFlyer* team is using advanced computer technology—specifically, computational fluid dynamics—to vastly reduce the airplane's drag and optimize the structure for long-range, exceptionally high-fuel-load flying.

MATERIALS: The thousands of pounds of fuel in *Voyager*'s four-section wings made them droop down to the runway, where they scraped against the ground during takeoff. In order to avoid the same problem, *GlobalFlyer*'s wings are constructed of a single 100-foot-long piece of reinforced composite.

DESIGN: Without horizontal tails to stabilize it, *Voyager* flexed and twisted in ways that made it hard to control. *GlobalFlyer* has complete tail assemblies, which dampen unwanted up-and-down movement.

BOOM AND TAIL

Each 40-foot-long boom holds landing gear and 5,454 pounds of fuel. Designers streamlined the tail assembly, because too much weight so far behind the plane's center of gravity would create instability.

WING SHAPE

The sailplane-like airfoil design of the 114-foot-long, 400-square-foot wings gives the *GlobalFlyer* outstanding glide performance.

JET ENGINE

The Williams FJ44-3 business-jet engine is modified to use military-grade JP-4 fuel, which has a lower freezing point than normal jet fuel.

DROGUE CHUTES

Undetachable chutes that add 20 square feet of equivalent drag can initiate a final descent or stabilize the aircraft in an emergency.

Header tank

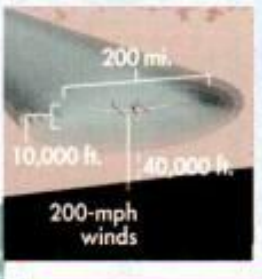
MAIN FUSELAGE

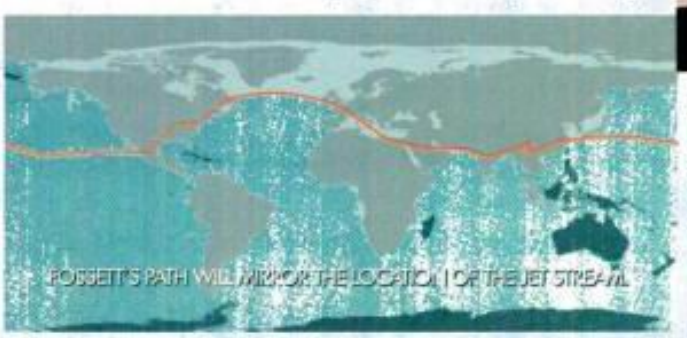
The center fuselage holds the header fuel tank, cockpit, engine mount and landing gear. Unlike *Voyager*, which flew at 11,000 feet, *GlobalFlyer* cruises at 45,000 feet and so requires a pressurized cabin.

Landing gear

FOLLOW THAT JET STREAM

The global jet stream dictates when and where *GlobalFlyer* flies. In winter, the jet stream moves to low latitudes and becomes turbulent; in summer, it's too northerly and weak. Spring and fall conditions balance wind speed, location and predictability.





ANATOMY OF A JET STREAM

The northern polar jet stream is a massive high-altitude air current, fueled by the temperature difference between the poles and the equator, blowing west to east across the Northern Hemisphere. Fossett must ride the jet stream if the trip is to have any chance of success.

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SHIP TO SHIP

Sea monster on the port side! Here's how the mightiest ship of our time would look in Nelson's spyglass.

H.M.S. *VICTORY*

Royal Navy 100-gun First Rate ship of the line, built from 1759 to 1765 and made of wood seasoned for 20 years. First action in 1778. Most famous engagement: under Admiral Horatio Nelson in the Battle of Trafalgar, 1805, when she carried 104 powerful guns. Still floating, fully restored, in Portsmouth, England.

FULL SAIL The crew co
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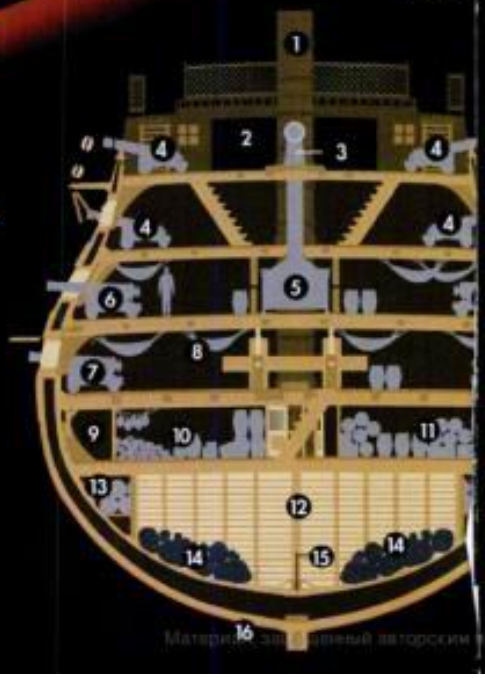
IT TOOK A FOREST Building the *Victory* required 60 acres worth of trees, most of them oak. Each mast was made from five to seven trees, its pieces secured by iron hoops. The tallest mastwood often came from North America.

HER MAJESTY'S ANATOMY Space was precious, and the ceilings not much higher than a man. Most of the crew slept in hammocks, while the Admiral's cabins featured dining and sitting rooms. Fully loaded, the hold stored several hundred tons of provisions, including 45 tons of biscuits and 50 of beer: The idea was to stock up for long periods at sea, possibly behind blockades. The carpenter's walk, a narrow space between hull and hold, allowed the woodworkers to repair damage from enemy shots. Copper sheathing protected the outer hull from rot, and it increased speed. Though the First Rate was massive, its expansive sails made it, in one historian's words, "not noticeably slower than the rest of the fleet."

1. Mainmast
2. Captain's cabin
3. Galley stove chimney
4. 12-pounder gun
5. Galley stove
6. 24-pounder gun
7. 32-pounder gun
8. Crew hammocks
9. Carpenter's walk
10. Carpenter's store
11. Boatswain's store
12. Main hold
13. Gunpowder and weapons store
14. Ballast
15. Limber passage
16. Copper sheathing



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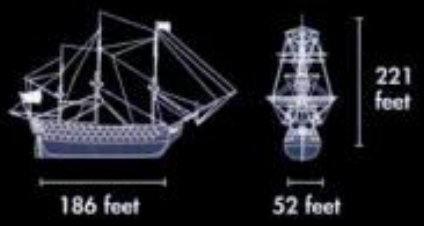
uld raise as many
n the *Victory's*
vsprit. One surviv-
tle of Trafalgar
om enemy shot.

A SHORT YET MIGHTY TALL SHIP

Though brief from bow to stern against the three-football-field length of a *Nimitz* carrier, and displacing a mere 3,500 tons to *Reagan's* 97,000, the *Victory's* mainmast stretches as high off the water as the communications gear atop the carrier's "island." It needed the height to accommodate its tremendous expanse of sail.



OWN THE HATCHES
y seas, the lower
s were closed to
flooding of the
ck.

FIREPOWER

19TH-CENTURY ORDNANCE

The Royal Navy didn't have the fastest ships, just the best guns and gunnery crews, which together could get off one shot per gun every 2 minutes. (The "pounder" rating refers to the weight of the cannonballs.)

68 POUNDER
Heavy, slow shot splintered the enemy's deck.

32 POUNDER
Range of a mile, could penetrate 2 feet of oak.

24 POUNDER
Twelve men ran each of the 28 middle-deck guns.

12 POUNDER
Small shot, or grape, for antipersonnel use.

FULLY LOADED
A massive floating gun deck, yet fast.

21ST-CENTURY ORDNANCE

Along with a mighty arsenal of offensive weapons, *Nimitz*-class ships wield a lot of defensive firepower, though no modern Navy can oppose U.S. carriers the way Japanese forces did during WWII. Next to come: unmanned drones.

F/A-18 HORNETS
All-weather attack fighters also aid ship defense.

F-14 TOMCATS
Specialize in ground attacks, could be phased out by '07.

SH-60 SEAHAWKS
Anti-submarine warfare and search and rescue.

S-3B VIKINGS
Multipurpose; electronic warfare and search and rescue.

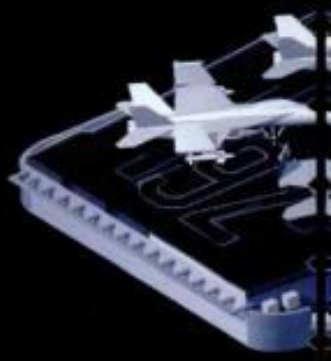
E-2C HAWKEYES
Tactical battle management, command and control.

EA-6B PROWLERS
Neutralize enemy radar and communications.

DEFENSIVE

RAM SYSTEM
Packs 21 missiles that destroy incoming high-speed targets.

NATO SEA SPARROW MISSILES
Self-defense missiles with a range of 30-plus miles.



A BULBOUS BOW Redesigned bow provides added stability during flight operations and improved hydrodynamics for better propulsive efficiency.

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CREW

H.M.S. *VICTORY*

At Trafalgar, the *Victory* had a crew of 819, including 146 Royal Marines, a surgeon and 31 boys.

OFFICERS: 57

(1 = 10 MEN)

MARINES, SEAMEN AND SERVANTS: 762

U.S.S. *RONALD REAGAN*

A crew of almost 6,000, including the 2,480-person air wing, includes 526 officers, two lawyers and a dental department 20 deep.

OFFICERS: 160

SHIP'S CREW: 3,350

AIR WING: 2,480 (366 OFFICERS)

THE BOSS GETS A BETTER VIEW

A redesigned "island" on the *Reagan* gives the Primary Flight Control group a 270-degree view, enabling better coordination of flight deck operations.

HOW THE FAT CATS FIRE

Four 300-foot-long, steam-powered catapults—called the Fat Cats—accelerate an aircraft to 165 mph in only 3 seconds. A T-bar on the plane's nosegear attaches to a shuttle, which is fired down the line by a huge piston.

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U.S.S. *RONALD REAGAN*

The ninth in the *Nimitz* class, the $4.5 billion *Reagan* was commissioned in July. Upgrades include a bulbous bow for added stability, a repositioned landing strip and stronger arresting cables for incoming planes. A new fiber-optic-based control system governs everything from phones to the 3.5-million-gallon jet-fuel system, with touchscreen monitors replacing old-fashioned analog gauges.

TRICKY LANDING Three upgraded arresting cables handle heavier aircraft. Aiming for the middle cable, pilots gun engines so they can take off again if they miss. (Runways are cleared first.)

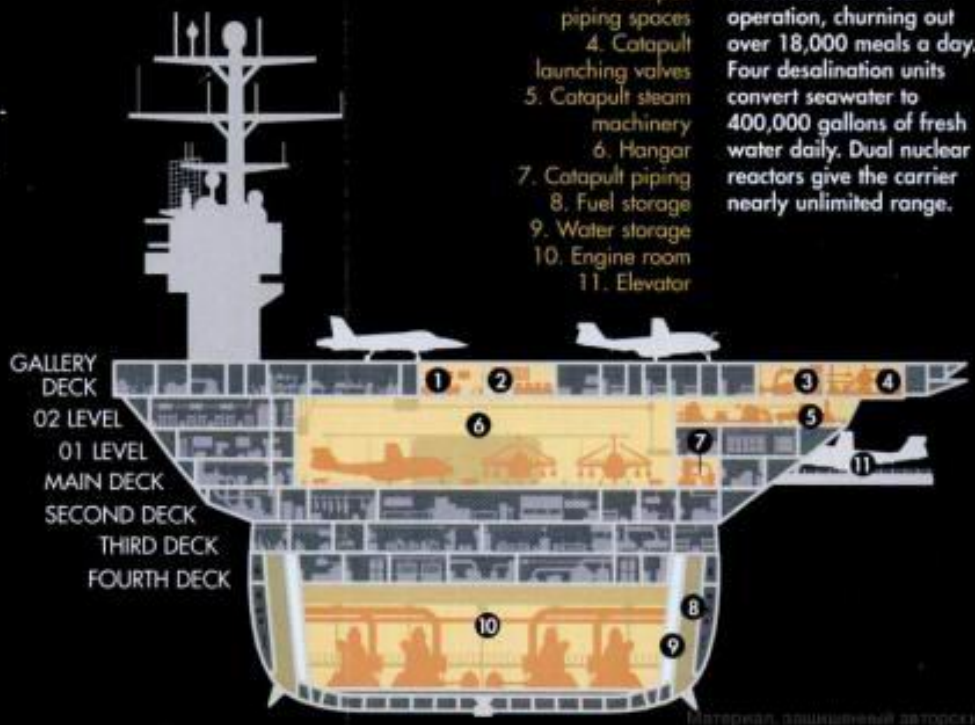
DECK REDIRECTED Shifting the orientation of the landing area less than 1 degree to port allows for simultaneous takeoffs and landings.

huttle

IN THE BELLY OF THE BEHEMOTH

Between the flight deck and its cavernous hangar, the *Reagan* can hold more than 80 aircraft. Crew quarters are still tight: Carriers pack 60 to a room, with bunks stacked three high. The mess is no small operation, churning out over 18,000 meals a day. Four desalination units convert seawater to 400,000 gallons of fresh water daily. Dual nuclear reactors give the carrier nearly unlimited range.

1. Air operations office
2. Carrier air traffic control center
3. Catapult piping spaces
4. Catapult launching valves
5. Catapult steam machinery
6. Hangar
7. Catapult piping
8. Fuel storage
9. Water storage
10. Engine room
11. Elevator



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THE HOUSE THAT PHILLY BUILT

ENGINEERED TO THRILL FANS AND INTIMIDATE OPPONENTS, THE EAGLES' NEW NEST IS TRICKED-OUT AND READY TO RUMBLE.

$330 million will buy one heck of a pad. Just ask the Philadelphia Eagles. This month, they move into their new home, a brand-new, state-of-the-art multimedia coliseum. Here's an inside look at Lincoln Financial Field, the most high-tech stadium in the NFL. —JENNY EVERETT

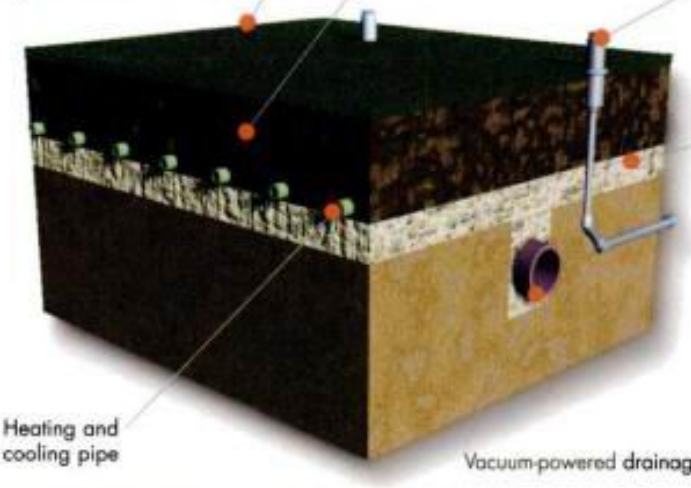
LED boards around the outside of the stadium broadcast the game to tailgating (or ejected) fans.

The 700-plus speakers hidden under the overhangs are angled to reduce echoing. Controlled by computers, the system allows section-specific messaging and adjusts speaker volume to compensate for crowd noise—which during playoff games can reach 105 decibels. That means you'll hear the announcements no matter how rowdy the stands get.

Sideline seats are just 60 feet from the playing field.

ROBO-FIELD

The field is seeded with Kentucky bluegrass, which can be cultivated to remain soft and flat in all weather conditions. A mixture of water and glycol travels through 28 miles of subterranean plastic hoses to warm or cool the field according to sun and shade conditions. When it rains, a vacuum-powered drainage system sucks out moisture to prevent oversaturation.



Lincoln Financial Field is designed for socializing, with three open plaza areas where fans can congregate. At Veterans Stadium (the Eagles' former home), the only place large enough for the notoriously enthusiastic fans to gather was the basement holding cell.

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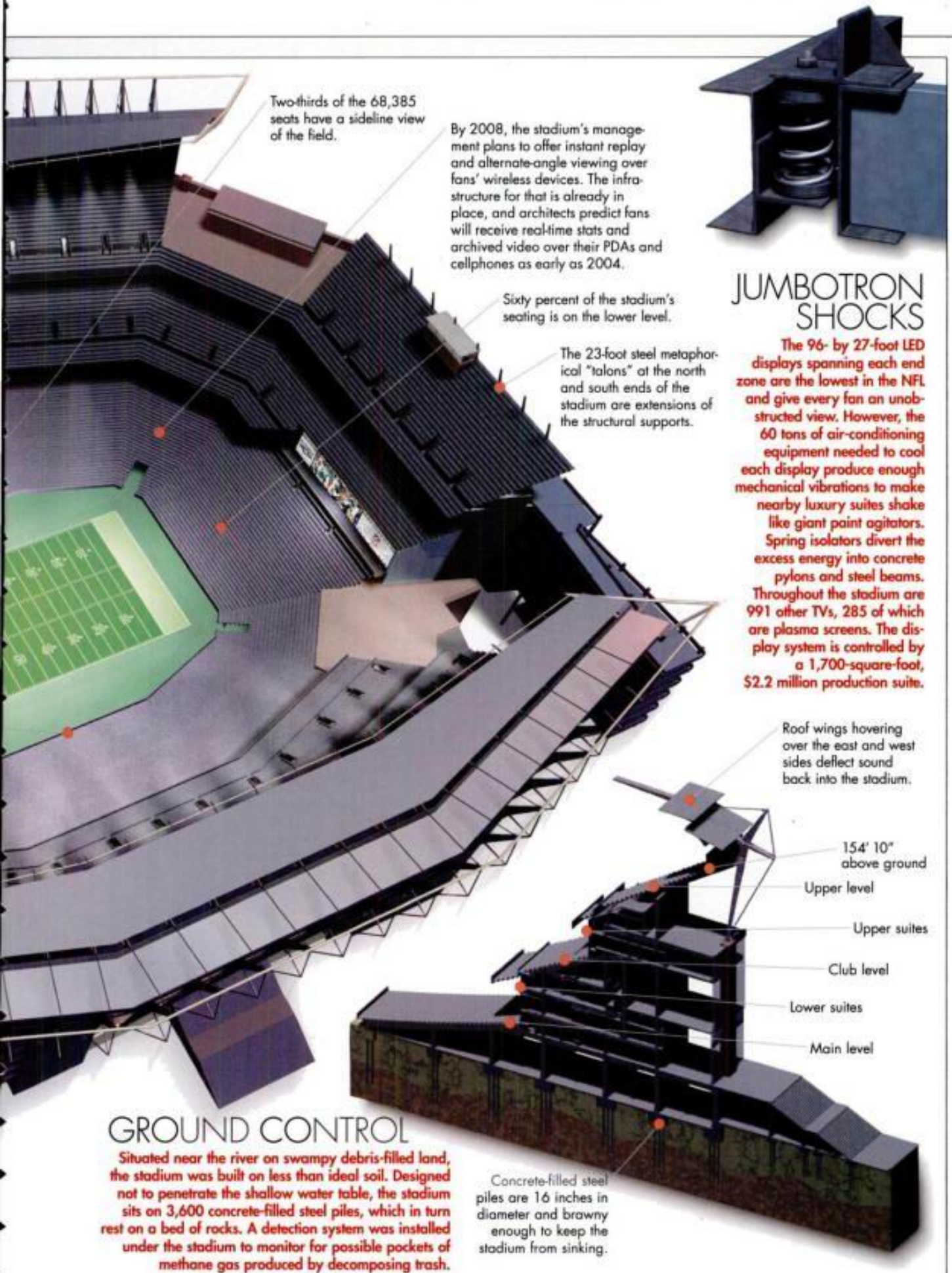

JUMBOTRON SHOCKS

The 96- by 27-foot LED displays spanning each end zone are the lowest in the NFL and give every fan an unobstructed view. However, the 60 tons of air-conditioning equipment needed to cool each display produce enough mechanical vibrations to make nearby luxury suites shake like giant paint agitators. Spring isolators divert the excess energy into concrete pylons and steel beams. Throughout the stadium are 991 other TVs, 285 of which are plasma screens. The display system is controlled by a 1,700-square-foot, $2.2 million production suite.

GROUND CONTROL

Situated near the river on swampy debris-filled land, the stadium was built on less than ideal soil. Designed not to penetrate the shallow water table, the stadium sits on 3,600 concrete-filled steel piles, which in turn rest on a bed of rocks. A detection system was installed under the stadium to monitor for possible pockets of methane gas produced by decomposing trash.

INFOGRAPHICS BY MIKA GRONDAHL

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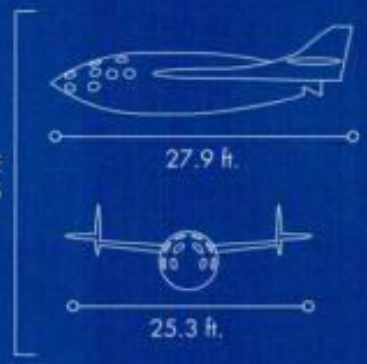
THE NEW WAY TO SPACE

This is a spaceship? It looks almost spindly—and where are the massive vertical fuel tanks of space vehicles past? That, of course, is the point: The small, light craft is relatively inexpensive to build, and with its piggyback configuration it requires far less fuel to reach 62.5 miles. This launch strategy, along with a massive rear wing that flips up during reentry, makes SpaceShipOne the most innovative craft gunning for the X Prize.



BURNING RUBBER
The ship is powered by a hybrid rocket system fueled by HTPB, a rubber-based compound, and nitrous oxide (laughing gas). On ignition, high-pressure nitrous in the oxidizer tank washes over heated rubber fuel in the motor case, igniting it and creating thrust.

AIRBRAKES
At 220,000 feet on the descent, the pilot lifts the tails so they're at a 65-degree angle to the body. The tails steer and stabilize the craft through reentry, while the wings and fuselage act as an airbrake.

STATS

CAPACITY
2 passengers + pilot
TOP SPEED
Mach 3.5 (launch), Mach 3.3 (reentry)
LANDING SPEED
80 mph
MAX ALTITUDE
62.5 miles
PEAK G-FORCES
3-4 Gs (launch), 5.5 Gs (reentry)
COST
$20-$30 million (est.)

1
White Knight, with SpaceShipOne attached underneath, takes off like a regular airplane.

2
After it is dropped by the White Knight at 50,000 feet, SpaceShipOne points upward and fires its hybrid rocket.

3
After a 65-second burn expends its fuel, SpaceShipOne continues on a 4-minute weightless parabolic arc above the atmosphere.

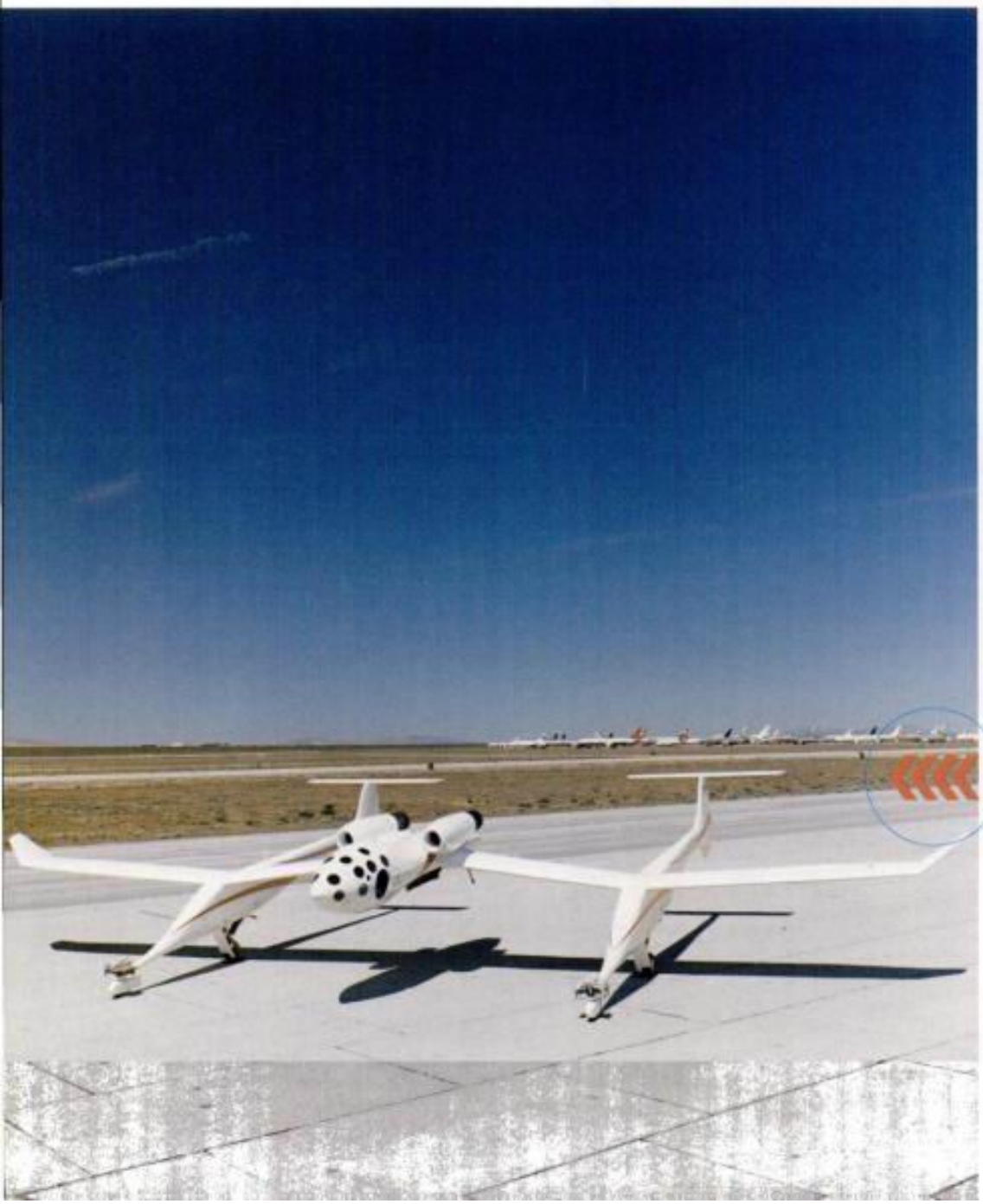
4
The "feathered" wings effectively make SpaceShipOne a giant shuttlecock; the craft drops like a stone, its body leading the way.

5
At 80,000 feet, the wings lower and SpaceShipOne turns into a glider. It lands horizontally at the same airstrip it departed from.

INFOGRAPHIC BY **JASON LEE**

THE ROCKET

Passengers aboard SpaceShipOne (right) will experience 3.5-G acceleration on the ride up to 62.5 miles—attributable to the vehicle's light weight (approximately 6,000 pounds) and fiercely powerful hybrid rocket engine. That will be an ordeal for even the heartiest adventurer: Late test pilot Milt Thompson said of the X-15, which offered a comparable ride, that it was the only airplane he ever flew in which he was "glad when the engine quit." The three-seat SpaceShipOne will be trundled up to space via the White Knight mother ship (below right). The passenger craft attaches to the White Knight's belly for the first 50,000 feet of the journey.



THE LAUNCHER

The White Knight (left), powered by two used jet engines culled from an Air Force trainer ("the cheapest engines I could find," says the designer), shares many parts with SpaceShipOne and can be used as a simulator for the smaller vehicle. A new avionics system (above) has multiple display modes for diagnostic and navigational data.

CLOCKWISE FROM TOP: COURTESY SCALED COMPOSITES; MISHA GRAVENOR; COURTESY SCALED COMPOSITES; MISHA GRAVENOR

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[SURFACE]

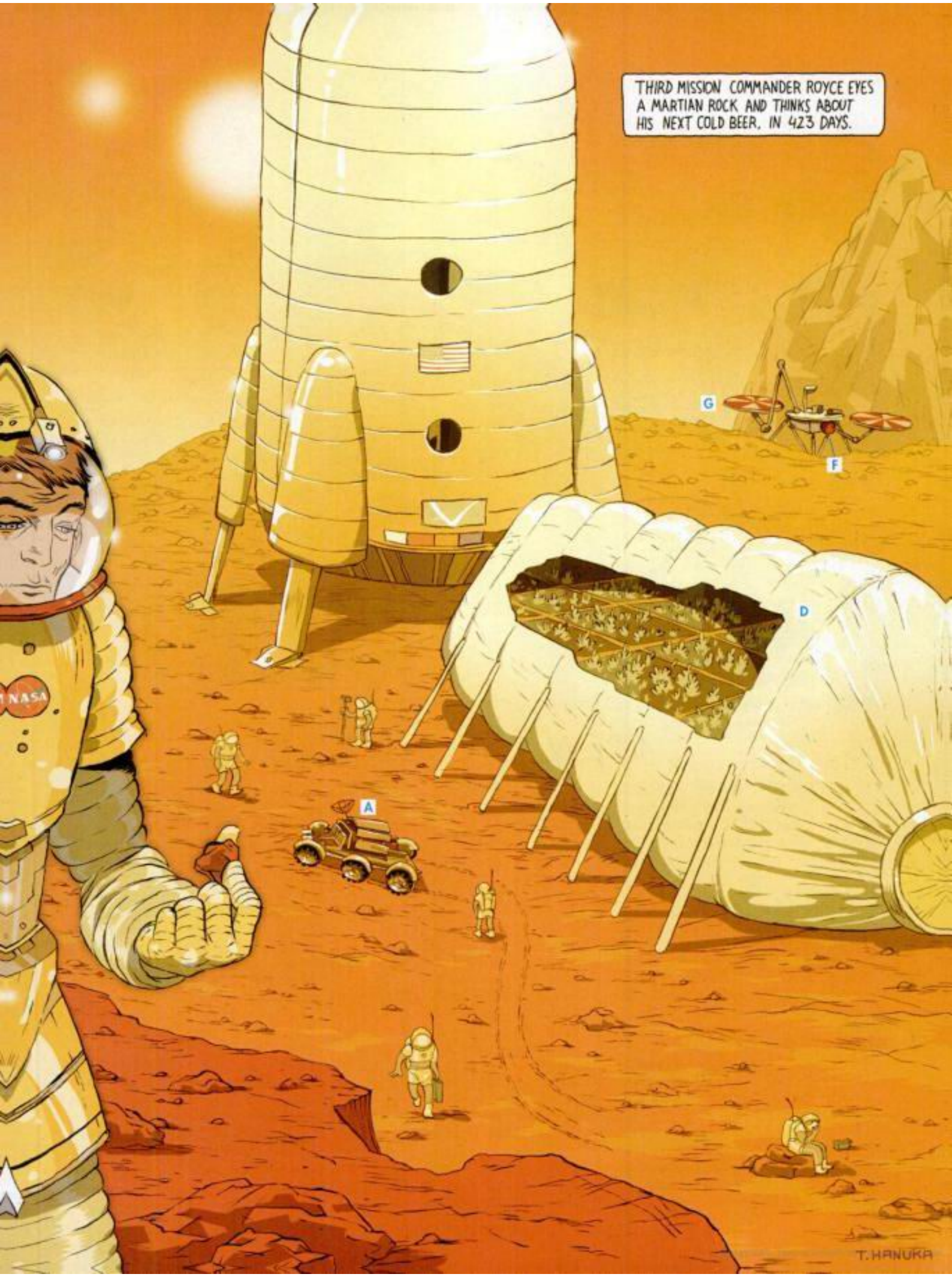
AFTER AS MANY AS NINE MONTHS in confinement en route, the crew will be relieved to get out and do some field work. Astronauts will cruise around near the base in open-top rovers (A), powered by fuel cells or photovoltaics, that were dropped off by an earlier Mars supply mission. For longer sorties, NASA plans to develop pressurized rovers capable of eight-hour jaunts.

Next-generation space suits (B) will be much less rigid and cumbersome than the current fashion, which is designed mostly for zero-G activity. Astronauts might wear peel-off films that would allow them to discard dust-coated outer layers of their suits before entering the habitat. New drills and burrowing probes will be used to search for subsurface water at base camp. Near the Martian ice caps, robotic thermal probes (C) will dig down to study the composition of Martian water. To power surface activities, NASA might need a nuclear reactor, which for safety would be installed up to a kilometer away from the main base.

Conserving energy and resources will still be critical, though, so NASA is sponsoring research on building recycling systems for air, water, waste and power. The NASA Specialized Center for Research and Training in Advanced Life Support at Purdue University is developing a system that uses tiny, spherical balls coated with waste-eating microbes. Wash water, and possibly water separated from urine through freezing and other chemical processes, would be channeled down from the top; the microbes would consume contaminants, leaving astronauts with clean water at the bottom. Air could also be recycled through the system. The microbes would degrade organic contaminants as the air travels up from below.

NASA-Purdue researchers are also working on energy-saving LED strips for plant growth. These "lightsicles" would illuminate from the bottom up, with each new light switching on as the plant grows. They could be used in an inflatable greenhouse (D), or, to protect plants from surface storms, in Martian caves or synthetic berms.

The crew pictured here isn't the first to land on Mars: The launch structure of a prior mission's ascent vehicle—which lifted off the planet and linked up with an orbiting Earth-return craft—remains (E). The exit fuel was produced on Mars, thanks to a converter (F) like the one now under development at Pacific Northwest National Laboratory. This device reacts atmospheric carbon dioxide with stored hydrogen to produce methane fuel and water. Through electrolysis, the water can then be separated into oxygen and hydrogen—the latter goes back into the conversion process. The converter would be the size of a basketball; it would be powered by a solar generator (G).—GREGORY MONE


THIRD MISSION COMMANDER ROYCE EYES A MARTIAN ROCK AND THINKS ABOUT HIS NEXT COLD BEER, IN 423 DAYS.
NASA
G
F
D
A
T. HANUKA

toes increased in the population.

The strategy works well as a computer simulation, but implementing it is another matter. For a 20-generation eradication, the lab-modified HEG mosquitoes would need to constitute 1 percent of the wild population at the start of the experiment, and be dispersed evenly throughout an entire continent. "With existing methods, eradication is not an option, especially not in sub-Saharan Africa," says geneticist Marcelo Jacobs-Lorena of Case Western Reserve University in Cleveland. Jacobs-Lorena cites the difficulty of determining the correct release points; miss a few bugs, and the population booms all over again.

Moreover, set free in the wild, HEG mosquitoes could create new and unexpected problems. "Once something is out there, can you control it?" asks Sujatha Byravan, executive director of the Council for Responsible Genetics. "You have to worry about it spreading to other mosquito species."

Many malaria experts doubt Burt's plan will work, but they agree that neither humans nor other creatures would miss *A. gambiae*. The mosquito is neither a significant pollinator nor a critical, reliable food source. "I doubt there'd be significant ecological consequences," says mosquito expert Frank Collins of Notre Dame University. Convincing the world of that is another matter. Governments, international health officials and citizens living in malaria-affected regions will all need to be sold on genetically modified mosquito extinction. Until then, keep swatting.—GREGORY MONE

THE POPSCI OPINION POLL

MALARIA KILLS AN ESTIMATED 1 MILLION PEOPLE EVERY YEAR. SHOULD SCIENTISTS AND POLICY MAKERS ATTEMPT TO GENETICALLY ENGINEER THE ERADICATION OF ITS PRIME CARRIER, THE MOSQUITO?

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SPACE EXPLORATION

DÉJÀ MOON

It's close to home, potentially lucrative, and expecting visitors.

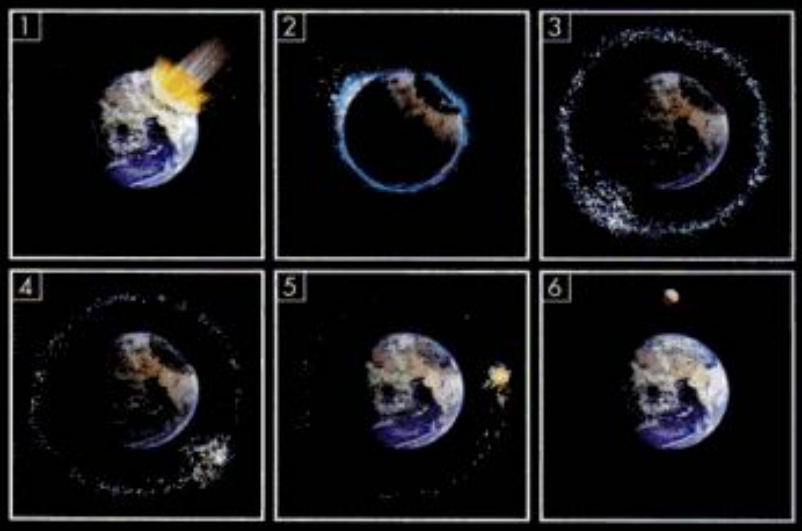
More than 30 years after Neil Armstrong walked on the Moon, the pock-marked satellite is once again the place to be. Europe, China, Japan and India all plan to take an unmanned Moon shot, starting with the European Space Agency's SMART-1 orbiter in July. Why the renewed interest in the Moon? For recent space explorers, such as Japan and China, it's the most logical, closest and cheapest destination. For scientists, a fiery debate continues over the Moon's origins and the possibility of ice water lurking in dark polar craters. And finally, there's the profit motive: A California company plans to use its first-ever, government-issued Moon license to collect images for, among other things, video games. Indeed, Moon mania is back.—LARRY O'HANLON

PROBING THE ORIGINS *SMART-1*

Set to launch in July, the unmanned SMART-1 craft (the first of the Small Missions for Advanced Research and Technology) will test a novel ion propulsion system for future ESA missions to Mercury. The ion drive uses solar-generated electricity to charge and heat xenon gas that then shoots from the spacecraft, thrusting it in the opposite direction. SMART-1 will also experiment with deep-space communications equipment to help scientists track spacecraft at a greater distance from Earth. And a novel 450-gram mini-camera will snap color images of the lunar surface while spectrometers analyze infrared, visible light and X rays reflected from the Moon's surface. The data should help geologists explain rock composition differences between the cratered highlands on the Moon's dark side and the lava-covered basins that face Earth. It may also shed light on the popular theory that the Moon is actually a 4.5-billion-year-old chunk of carnage left over from a colossal asteroid-Earth collision (see graphic, below). The $109 million craft will launch on an Ariane 5 rocket from Europe's space port in Kourou, French Guyana.

MISSION RISK: The new Ariane 5 rocket launchers have failed in four out of 15 missions. In contrast, the retired Ariane 4 failed in four of 166 flights.

THE GIANT-IMPACT HYPOTHESIS An asteroid smashes into Earth (1), spraying mantle material and debris into space. A dust cloud forms (2), then disperses outward in an orbiting ring (3). The material condenses, swallowing its own tail (4), gradually taking a spherical shape (5) and forming the Moon (6).



ILLUSTRATIONS BY GARRY MARSHALL; MOON IMAGE COURTESY JPL

MOON FOR SALE *Trailblazer*

Commerce often follows on the heels of science, and space exploration is no exception. Trailblazer will be the first commercial spacecraft to orbit the Moon. Lifting off from Kazakhstan's Baikonur Cosmodrome in October or November, the craft—essentially a flying camera—will send home stunning HDTV images of the Moon during its 90-day orbit, says Dennis Laurie, CEO of TransOrbital in San Diego. The images will be used to make video games, movies, maps and educational products. (To collect these pictures, TransOrbital had to obtain an imaging license from the National Oceanic and Atmospheric Administration and the Department of Defense.) Some people paid the company $2,500 per gram to include business cards, cremated remains, jewelry, artwork and other items in Trailblazer's payload. The artifacts will be packed into a titanium time capsule designed to survive the craft's crash landing near the South Pole where the mission will likely end. Essentially, lunar litter.

MISSION RISK: Will consumers have an appetite for TransOrbital's lunar products?

MOONQUAKE MISSION *LUNAR-A*

This $100 million Japanese lunar probe will break new ground, literally. The orbiter—about the length of an upright vacuum cleaner—is equipped with a pair of missile-shaped penetrators. Guided by de-orbit rocket engines and built to withstand an impact force of 10,000 Gs, the penetrators will smash into the Moon's powdery, rocky soil at 250 to 300 meters per second and burrow to a depth of 1 to 3 meters. One seismometer-equipped penetrator will be deployed on the far side of the moon and another on the near side. Both will record a year's worth of moonquakes that could reveal details about the Moon's interior structure and the size of its core, explains spacecraft data archivist David Williams of NASA's Goddard Space Flight Center. And the penetrators' heat-flow sensors should give clues about radioactivity inside the Moon by measuring thermal waves emanating from its core. Expect an August or September 2004 takeoff from the Kagoshima Space Center in Japan, says project manager Hitoshi Mizutani of Japan's Institute of Space and Astronautical Science.

MISSION RISK: If the penetrators strike rock, the research will be spoiled.

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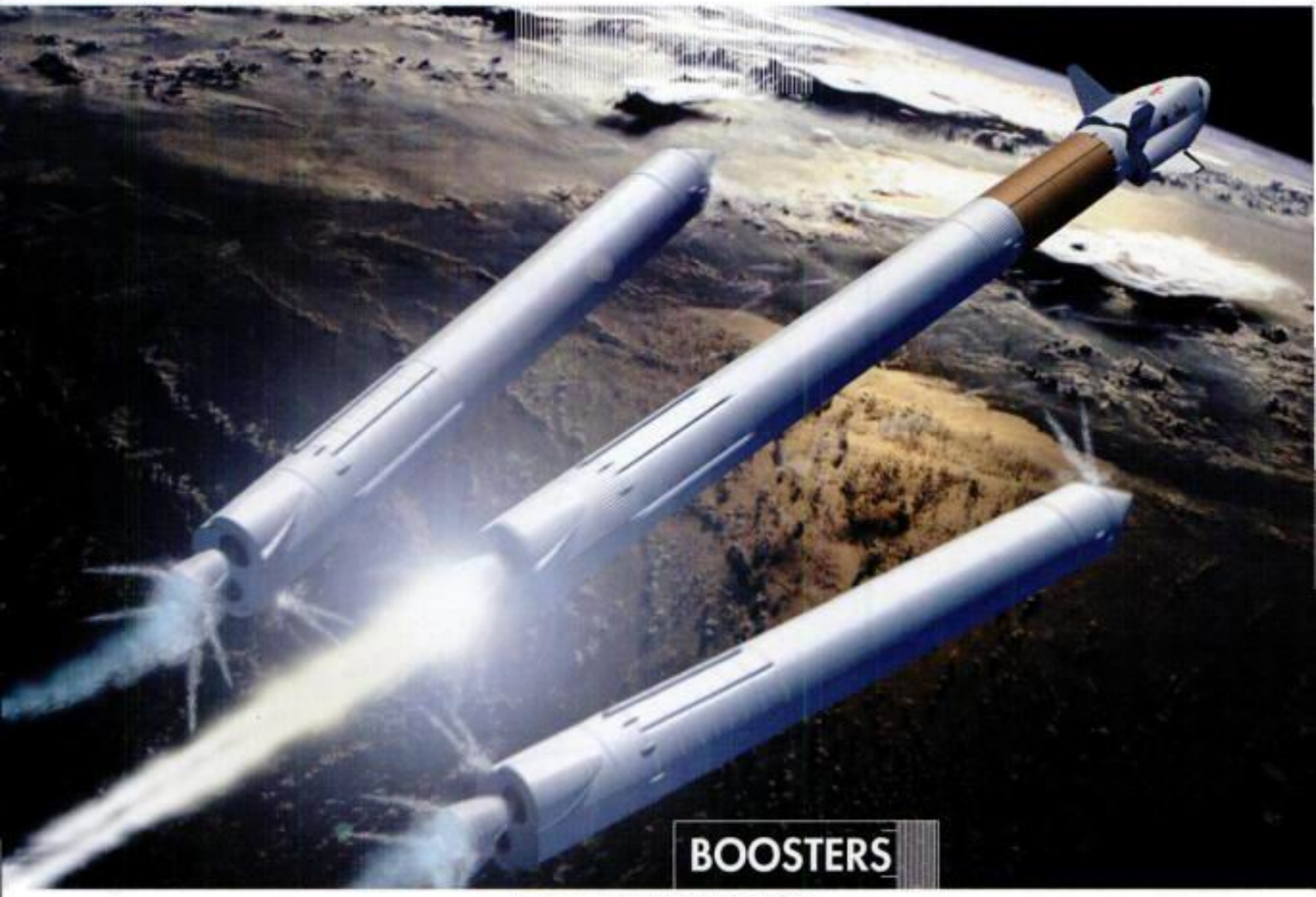
SPACE SHUTTLE: THE NEXT GENERATION

EVEN IF IT'S FIXED, THE DISASTER-PRONE SHUTTLE MAY NOT BE ALLOWED TO FLY AS LONG AS NASA REQUIRES. THE AGENCY'S PLANS TO REPLACE IT ARE IN DISARRAY. BUT THERE ARE CONCEPTS ON THE DRAWING BOARD.

BY BILL SWEETMAN
ILLUSTRATIONS BY BOB SAULS / FRASSANITO & ASSOCIATES

FLYBACK

Northrop Grumman's proposal employs two liquid-fueled flyback boosters and a central rocket to push either a crew- or payload-carrying vehicle into orbit. The central rocket and fuel tank also return to Earth for future use, creating a completely reusable system. By contrast, the current shuttle's external fuel tank burns up as it reenters the atmosphere after being jettisoned.



Until a new **reusable launch vehicle can be developed, NASA will launch the small Orbital Space Plane—mostly as a taxi to the International Space Station. OSP will set off atop a standard Atlas V or Delta IV rocket or using the three-booster, liquid-oxygen/liquid-kerosene-fueled rocket configuration shown here. Only the crew vehicle is reusable.**

fragile tile system that is supposed to keep the shuttle from burning up during reentry.

The excessive weight and size of the orbiter is also a drawback. When the system was built, the Pentagon insisted on the ability to snag disabled satellites and return them to Earth, which required a larger, sturdier orbiter. But the shuttle has hardly ever been used for that. And NASA's goal was to send the shuttle into space 30 to 50 times each year on science and satellite launch-and-recovery missions for the public and private sectors. The agency figured the cost of maintaining the big payload and oversize orbiters would be more than offset by a long line of customers who would keep the shuttle and its crew busy. But in reality, the shuttle has averaged only five launches a year, with few paying customers; the economies of scale NASA had hoped for never materialized. "Rarely do you see an instance where state-of-the-art technology enters service," says Keith Cowing, editor of Nasawatch.com. "You live with whatever moment in time you froze your design."

As early as 1986 federal officials tried to replace the shuttle with a spacecraft called the National Aerospace Plane. This sleek vehicle was supposed to look like a plane and fly into orbit powered by an air-breathing engine called a supersonic combustion ramjet, or scramjet. That effort was canceled in 1993 when it became clear that the decision to pursue scramjet technology was a bit premature. Since then, there have been a number of other ideas under consideration (see sidebar, page 81) but SLI produced a series of designs that offered for the first time a fully formed picture of what the future shuttle is likely to be. Concepts were designed by Lockheed Martin, Northrop Grumman, Boeing and Orbital Sciences, among others. All of them use boosters to get payloads into orbit, but that's where the similarities to the shuttle end. For instance, an intriguing design was the Boeing "bimese" reusable launch vehicle (RLV), which has two nearly identical winged rockets stacked together with the orbiter or payload container perched on top of the upper rocket. The reusable launch vehicle takes off vertically with all engines firing. When the fuel runs out in each booster rocket, it separates from the RLV and glides back to Earth to land on an airstrip. The advantage of the bimese approach is that because the two rockets are virtually indistinguishable, it's only necessary to build, test, operate and maintain one winged booster design. With a single set of engines, landing gear, controls and other systems, it's a much simpler spacecraft to manage than the shuttle.

Northrop Grumman was particularly busy during SLI. It proposed several vehicles, including a launcher that uses an enormous jet, equipped with six engines and an oversize

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Northrop Grumman also proposed a system in which an enormous flying-wing airplane, powered by six of the largest available jetliner engines, would carry a reusable rocket to 40,000 feet and launch it in mid-air. A winged carrier would be relatively easy to build and operate, and it could carry the rocket down the Equator, where the Earth's spin helps kick rockets into orbit.

wing, to carry the booster to 40,000 feet, where it would disengage and fire its rockets for the final hop into orbit. And Northrop's collaboration with Orbital Sciences produced an RLV with two identical tank-shaped boosters seated below an orbiter-carrying, upper stage space plane. These so-called flyback boosters are fitted with jet engines that power them back to Earth after the boosters rocket the upper stage above the atmosphere.

The vehicle shown on our cover, Andrews Space & Technology's Gryphon concept, is farther reaching. A plane-like launcher accelerates an orbiter to Mach 6 before a high-altitude release. Gryphon's innovative propulsion system uses liquid oxygen, drawn and compressed from the air, as fuel.

What's most significant about the SLI contenders is that the developers have engineered out all of the most gaping shortcomings in the current shuttle design. For one thing, the outdated solid rocket boosters—which require intensive reconstruction after each use—are gone, replaced by modern liquid-fueled rocket engines that mainly operate on hydrogen or kerosene; they're much safer because they can be shut off or throttled back after they ignite. Another long overdue improvement: SLI engineers have eliminated the delicate and precarious heat-resistant tile system. Instead, they use lightweight "shingles" with nickel-alloy skins over ceramic-fiber insulating blankets to protect the orbiter and upper-stage boosters from the dangers of reentry. Unlike brittle tiles, the metal-skinned shingles can be bolted securely to the airframe.

The computers in the next-generation shuttles have also been entirely revamped. To reduce the huge workforce needed to monitor every tiny event in the mission on the ground, each instrument that measures temperature, pressure, strain or vibration, among other things, in SLI vehicles has its own built-in computer, which doubles as a node on a network extending throughout the RLV. This network is made up of expert systems. These programs can constantly read signals from each computer on the network, isolate problems in real time and predict failures. Coupled with escape systems that today's shuttle lacks, the computers could possibly save the lives of the crew during an accident by signaling when to bail out or even by separating a crew capsule from other parts of the RLV that are in danger. "There are three levels to safety," says Doug Young, Northrop Grumman's space systems director. "The first is to make the vehicle more reliable. The second is to provide the crew with an escape system and the third is to make sure that the crew knows when to get out."

In perhaps the greatest break with the shuttle, the new launcher and orbiter designs are much more appropriately scaled to NASA's real needs—that is, for a slimmed-down and, at times, unmanned reusable launch vehicle. The current shuttle has rarely approached its full payload capacity and often a crew isn't required. SLI concepts contain a smaller orbiter that travels without a crew if the on-board task—

Our take on past spaceships at **www.popsci.com/exclusive**

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SPOT CHECK// Deployed from a sub's hull, Manta could dispatch tiny mine-seeking AUVs or engage in more explosive combat.

ROBOT SUBMARINES GO TO WAR

PART 2:

THE NAVY'S AUVs

Already, smart unmanned subs are set to replace dolphins as undersea mine sniffers. Next tech: mine detonation, remote sleuthing and robotic combat.

BY CARL POSEY

ILLUSTRATIONS BY JOHN MACNEILL

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Taipei

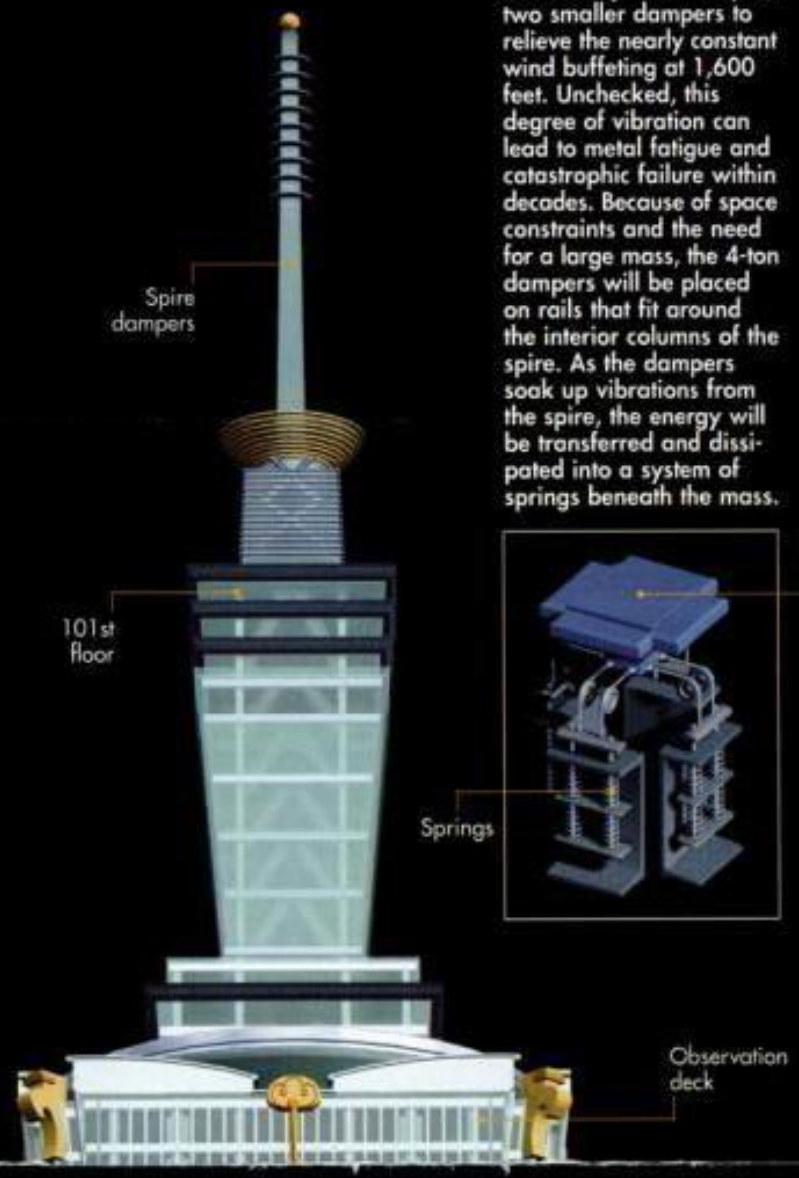
How the world's tallest building fights off earthquakes, typhoons and bad luck. By Brian Fortner

Taipei Financial Center Opens late 2004

THERE MAY BE NO LOCATION MORE ILL-SUITED TO AN outrageously tall skyscraper than Taipei, Taiwan. Not only does the city straddle the Pacific Ring of Fire, an arc of fault lines that erupt in serious earthquakes every decade or so, it also lies directly in the path of many of the typhoons that originate in the South China Sea. Nevertheless, when exterior construction ends late this year (the building will open in 2004), Taipei 101 will snatch the crown of the world's tallest building from the Petronas Towers in Kuala Lumpur, topping out at 1,666 feet, 183 higher than the Malaysian spires to the south.

Taipei 101 will be the first supertower built in an area where the incidence of both earthquakes and high winds calls for major design innovations. Each of these hazards necessitates a different, and in some ways contradictory, structural strategy: Buildings in earthquake zones must be ductile, flexing to absorb the energy of the shaking, whereas to resist high winds a building requires stiffness. The designers at Thornton-Tomasetti Engineers and Evergreen Consulting Engineering balanced these competing needs by integrating a myriad of structural innovations into Taipei 101, from a pliant steel exoskeleton for protection from earthquakes, to a giant hanging sphere called a damper, which prevents the structure from excessive swaying in high winds.

In addition to 21st-century engineering, the $1.64 billion tower also nods to ancient beliefs. The architects at Taipei-based C.Y. Lee and Partners designed a tower with eight distinct tiers emerging from a 25-story-tall base. Each tier opens upward as it rises, a form that signifies financial richness and everlasting vitality in Chinese culture. Because the Chinese consider eight an especially lucky number, the eight tiers consist of eight floors each. It should come as no surprise that Taipei 101 will house the Taiwan stock exchange as well as numerous prosperity-seeking financial companies. The extra luck should also come in handy when the inevitable typhoons and earthquakes hit.

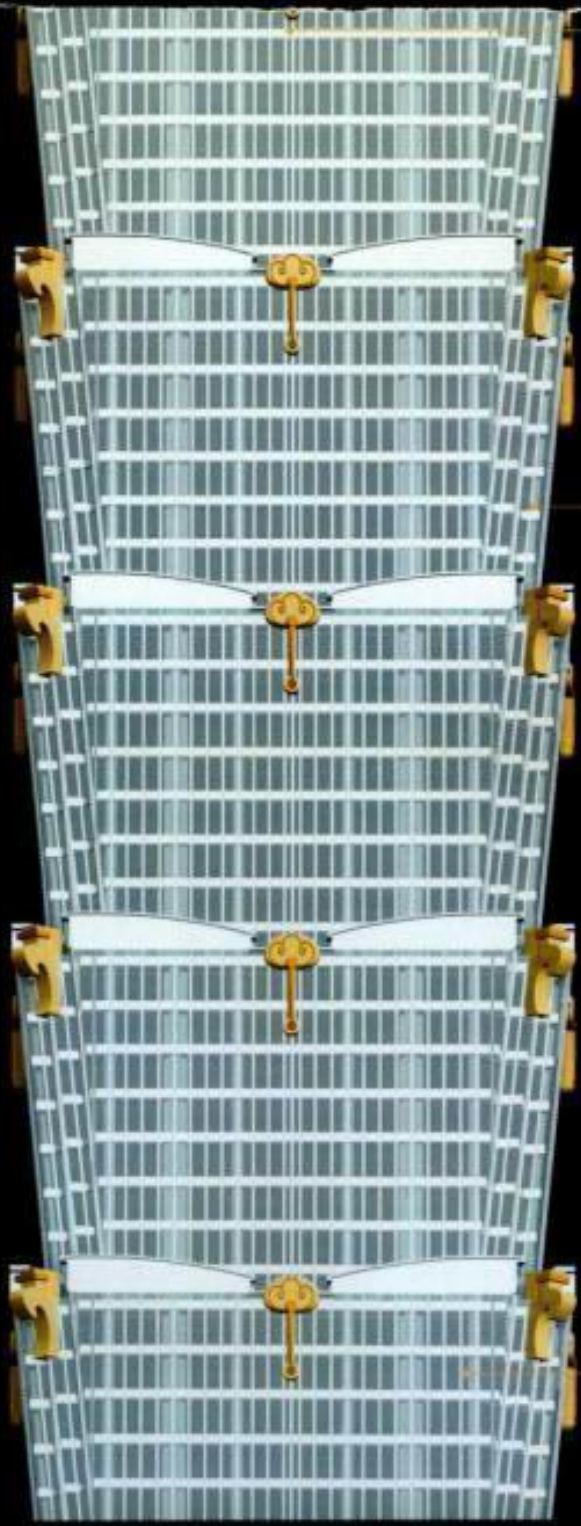


THE SPIRE

While a larger tuned mass damper protects the main structure, the tower's 200-foot spire will rely on two smaller dampers to relieve the nearly constant wind buffeting at 1,600 feet. Unchecked, this degree of vibration can lead to metal fatigue and catastrophic failure within decades. Because of space constraints and the need for a large mass, the 4-ton dampers will be placed on rails that fit around the interior columns of the spire. As the dampers soak up vibrations from the spire, the energy will be transferred and dissipated into a system of springs beneath the mass.

800-TON BALL AT THE 88TH FLOOR

Skyscrapers in earthquake zones are designed to flex to absorb seismic energy. But place a flexible tower in an area prone to high winds, and the swaying would make the uppermost floors feel like the deck of a cruise ship—not a comforting sensation when you're perched 1,500 feet in the air. Engineers at Motioneering skirted the listing problem by erecting the largest passive tuned mass damper ever, a mass tuned to swing at a specific frequency. Essentially an 800-ton pendulum strung from the 92nd floor, the damper acts as the building's inertia sink, swaying in high winds so the rest of the building doesn't. This $4 million sphere, supported by a sling of high-strength cables, will move only a few inches under normal circumstances. Eight viscous damping devices, similar to shock absorbers, attach to the ball at its equator. As the damper swings, its motion forces fluid in the damping devices through tiny orifices, which dissipates the wind's energy. In the case of a catastrophic event, defined as a once-every-century-strength earthquake or typhoon, the sphere will swing out 5 feet to meet a bumper ring, which will stop further swing with eight more viscous dampers called snubbers. This is the first tuned mass damper to be visibly integrated into a building's architectural design. A restaurant and balcony at the 88th and 89th floors will surround the ornate 18-foot-diameter sphere and provide a 360-degree viewing area, though public access to the restaurant (and the high-speed elevator that serves it) will be limited.



The building is designed with small sawtooth notches at the corners to help deflect strong winds.

On March 31, 2002, a 6.8-magnitude earthquake struck outside Taipei. Two massive construction cranes fell from the 56th floor, killing five construction workers. The structural components held up.

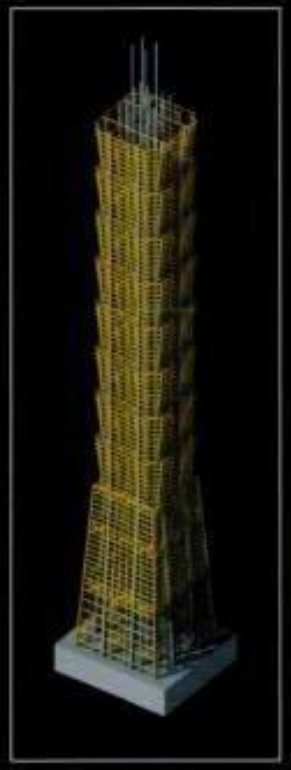
HOW IT STANDS UP

The building's frame is formed through the complex interplay of three distinct structural components, each designed to withstand a different type of load. Pairs of 8- by 10-foot supercolumns on each face of the building work in conjunction with 16 columns in the core to form the vertical support structure. The concrete-filled steel box supercolumns get progressively thinner between floors 25 and 77, and above level 62 they're made entirely of steel.

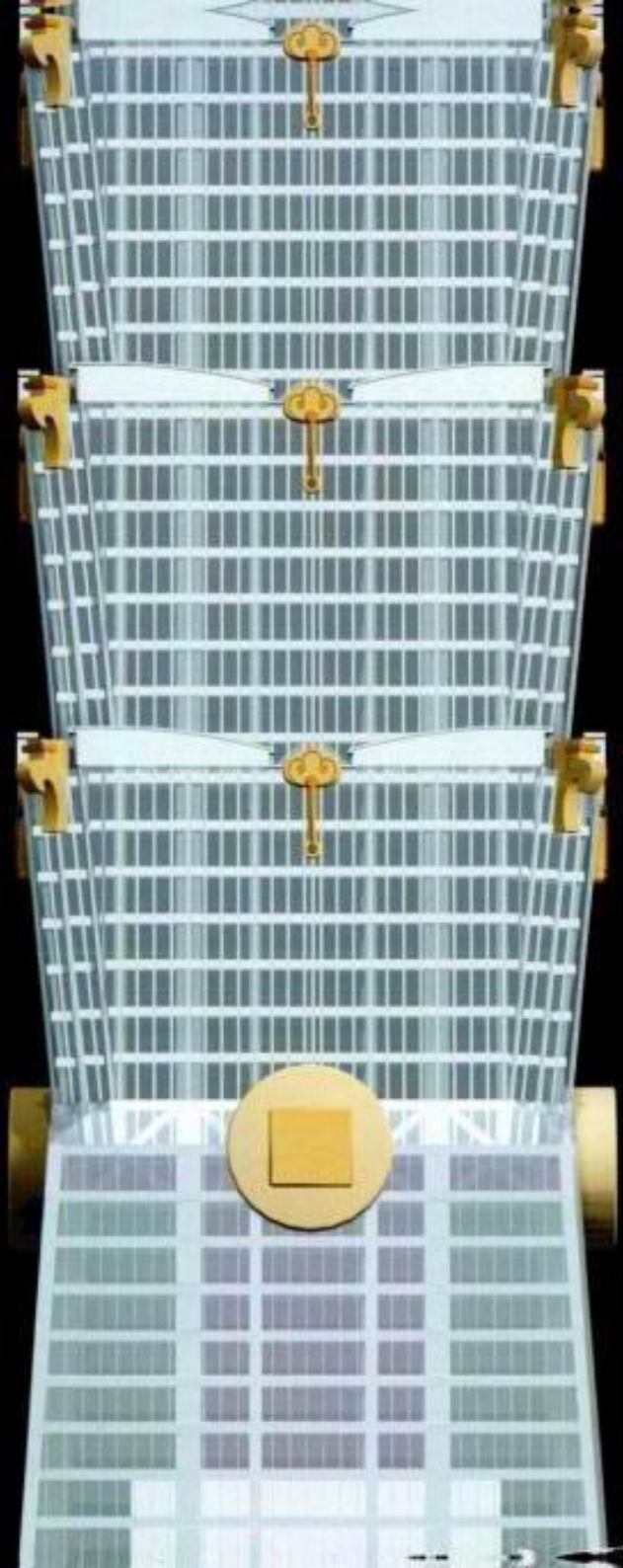
Wrapped around the supercolumns like an Euclidean spider's web is a moment-frame system, a ductile steel framework designed to bend during an earthquake. The frames support the outward slope of the building to make possible the repeating inverted-pyramid shape, a design element never before executed.

The real innovation, though, lies in the structure that holds all the columns together. Every eight floors, a dedicated mechanical floor contains massive floor-high steel outrigger trusses. These trusses connect the columns in the core to the supercolumns on the perimeter, effectively widening the building to help it resist overturning. It's like giving a skier poles—connect the central structure to a wide base, and it's much harder to knock over.

Vertical support comes from a central core of 16 columns and eight massive supercolumns on the tower's exterior (below left).



A blanket of moment frames is designed to bend during an earthquake (above center). The building's core is connected to the supercolumns via outrigger trusses (above right).



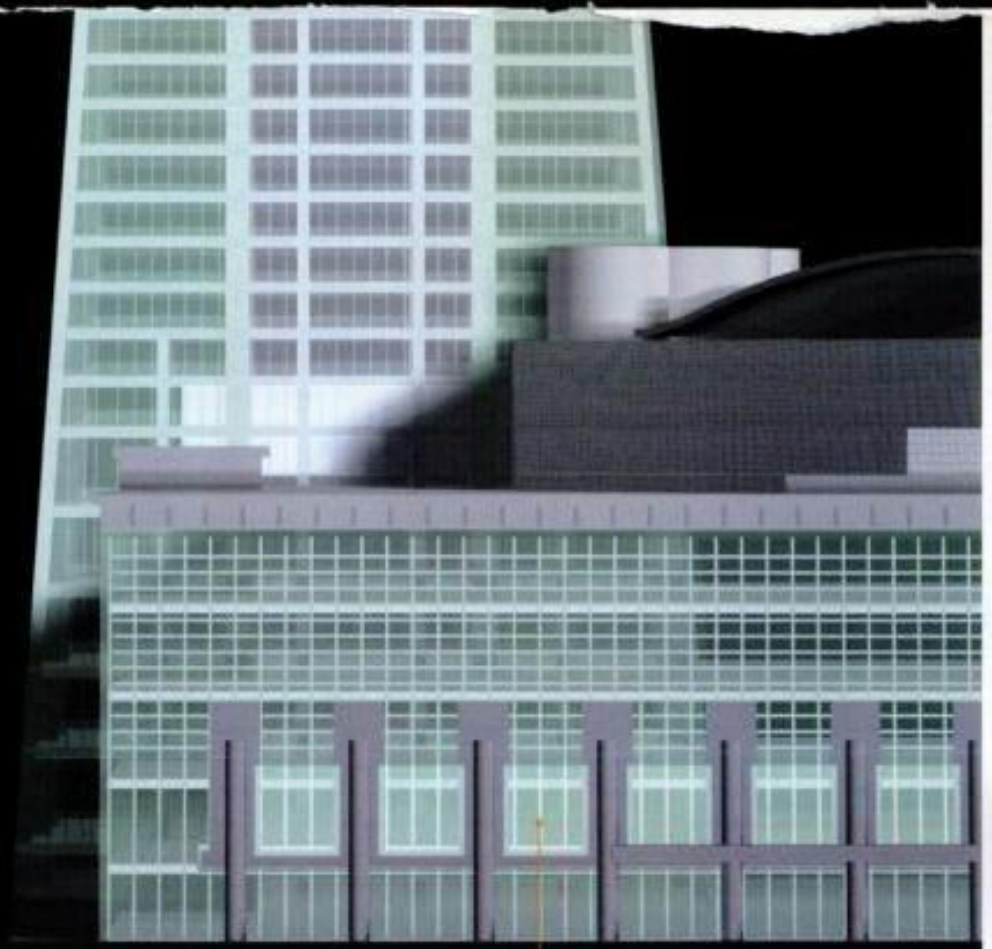
Every eight floors, the mechanical floor houses two large fireproof rooms at its corners—safety rooms that can shelter occupants in the event of a disaster.

THE ELEVATOR

It seems fitting that the world's tallest building be equipped with the world's fastest elevators. These two (the other 59 elevators will cruise at sub-record-breaking speeds), designed by Lerch, Bates & Associates, will whisk people to the 89th-floor observation deck in 39 seconds. Passengers will travel up at 3,300 feet per minute for about 10 seconds. Yet the ride down will be limited to around 2,000 feet per minute to show mercy for riders' inner ears. Brute elevator speed isn't hard to obtain: The challenge is to control that speed and develop adequate safety devices. Taipei 101's elevators, which cost more than $2 million each, will have the first pressurized cars, ceramic safety shoes for emergency braking and the first triple-stage buffer to cushion an emergency descent. Since uneven ambient temperatures warp an elevator's guide rails, computerized mass dampers will sense vibration and actuate small weights to adjust the roller guides—another first.

Aerodynamic exteriors (left) reduce drag.

If the elevators overshoot the bottom floor, the world's first telescoping buffers will cushion the fall. The three-stage system reduces the buffer length from 49 to 33 feet.

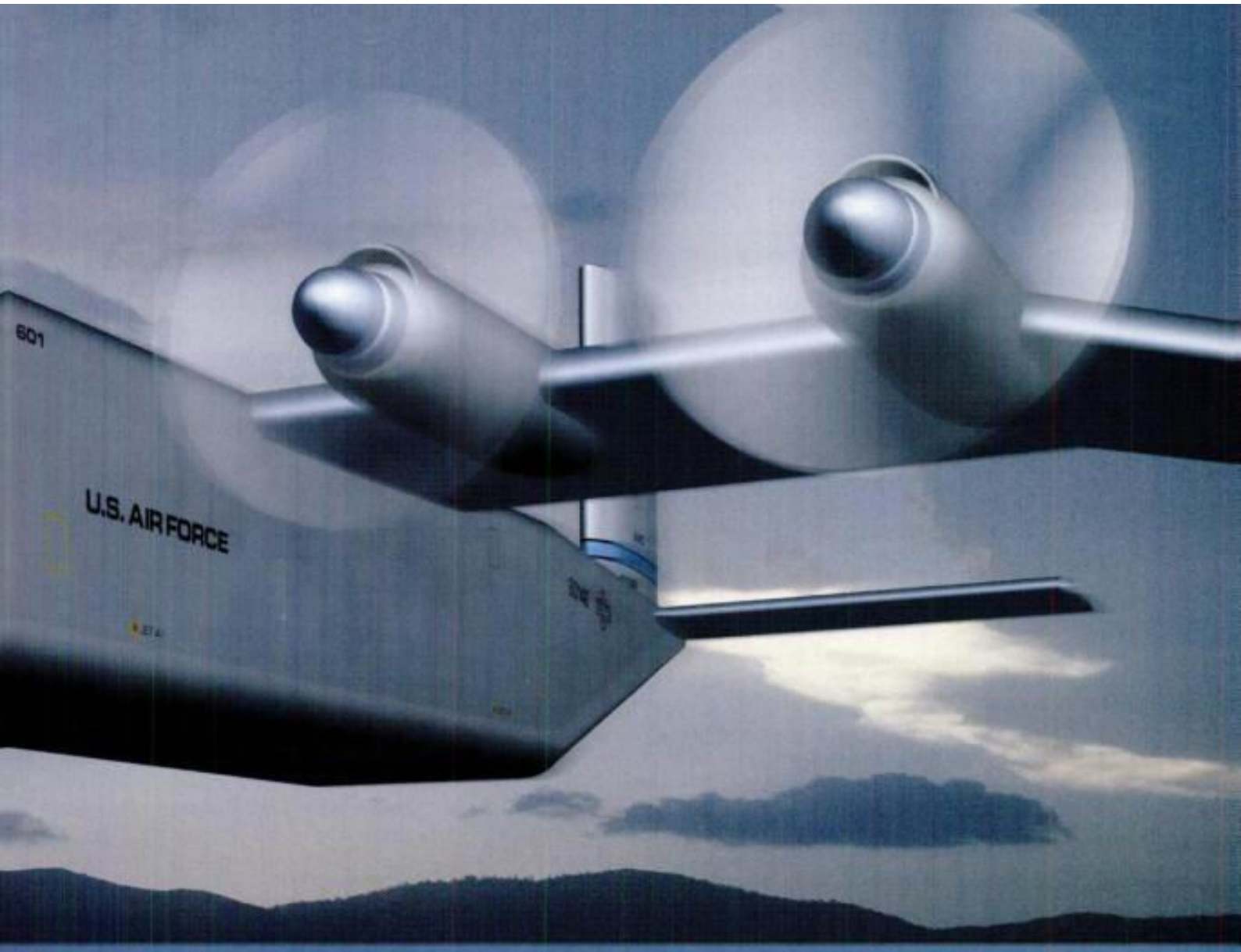


A six-story retail structure known as the Podium will flank Taipei 101. Like any mall not attached to the world's tallest building, it will contain shops, restaurants and entertainment arcades.

INFOGRAPHICS BY **MIKA GRONDAHL**

LOOK UP, BUT NOT WAY UP: BOEING'S MASSIVE CARGO CARRIER WOULD FLY

MONSTER AT 20



BY BILL SWEETMAN
Illustrations By Mika Grondahl

WERY, VERY LOW INDEED. HERE'S HOW.

FT.

IN THE SUMMER OF 1967, A GROUP OF INTELLIGENCE analysts gathered in the Defense Intelligence Agency's "Green Room," just outside of Washington, D.C., to puzzle over a strange spy satellite image. It showed a gigantic machine, something bigger than any known airplane, with wings that looked too short to fly, sitting in a fenced enclosure at Kaspisk, a small city by the Caspian Sea. "Jeez, that's a monster," said an Army colonel. "Yeah," said another, "the Loch Ness Monster." Someone added: "No, the Caspian. It's the Caspian Monster."

But what was it? How did it work? What did the Russians plan to do with it? The answers came slowly over the next decade: It was an ekranoplan, a new type of aircraft that exploited an aerodynamic phenomenon called ground effect to haul enormous payloads at high speeds over water. It was invented by Rostislav Alexeyev, a friend of Soviet Premier Nikita Krushchev. It was not yet working very well. And if the Amerikanski spies could think of a practical use for it, the Soviet military would have appreciated their advice, because Moscow politicians, keen to find a need for a project that owed its existence as much to connections as to any operational requirement, were hell-bent on ramming it down the armed services' throats.

After the Cold War ended, I asked a Russian aerospace engineer what he thought of the Monster and its descendants, which were being examined intensely by the Pentagon at the time. "A waste of money," he grumbled. "Every time it didn't work, [the designers told Moscow] it would work if it was bigger. And they got the money for it."

But they may have been on the right track. Today, engineers at Boeing are designing a cargo plane that, like the Caspian Monster, is designed to skim just above the water like a large sea bird. It's dubbed the Pelican, because it will use the same "wing-in-ground effect," or WIG, that the awkward bird does to glide almost effortlessly above the water. When applied to man-made flying vehicles, WIG aerodynamics represent a critical exception to a long-held rule of aviation—altitude equals efficiency. The reason most long-range airplanes are high-altitude jets is that flying in thick air at lower altitudes normally takes significantly more fuel. But if you get extremely close to the surface—around 50 feet or below, as a WIG vehicle would—a cushion of air generated by the plane's velocity helps support it in flight, so that the plane cruises even more efficiently than a high-altitude jet. The WIG aircraft Boeing is developing is bigger than the Caspian Monster: Its wingspan is about the width of the front of the Capitol. Boeing engineers are counting on the notion that enormous wings will provide more opportunity for the air below them to gently lift and propel the vehicle, allowing it to skate a mere 20 feet off the water at 300 mph.

The idea of an airplane that weighs as much as seven fully loaded Boeing 747s, and that doubles the distance it can travel by scooting over the ocean surface like a waterbug, may seem far-fetched. But the engineers at Phantom Works, the secretive Boeing think tank, have begun designing this enormous machine because the Pentagon has a major problem that has defeated many less harebrained efforts over the past 40 years. That problem? Mobility. The U.S. Army is a powerful force, but it is too large and has too much heavy equipment to move at a pace suitable for a fast-expanding conflict. For hauling the Army's equipment, ships are slow and airplanes are small—one division may have more than 300 70-ton Abrams tanks. Even the huge C-5 Galaxy cargo airplane can carry only two Abramses, and the entire Air Force has 126 C-5's.

Defense transformation is eventually supposed to result in a smaller, nimbler Army. But the Pentagon's goal is to move that force faster than it can today, putting a full brigade—3,000 people and 8,000 tons of equipment—on the ground anywhere in the world within 96 hours. John Skorupa, a retired Air Force colonel who now heads the strategic development office of Boeing's Advanced Airlift and Tankers division, dealt with this challenge in his previous job as commander of Air Mobility Command's Battle Lab. "It was clear to us that we never had enough airlift. When we looked at global reach lay-down"—airlifters' jargon for putting forces on the ground—"the airbridge took an enormous number of sorties to move a force of any significance."

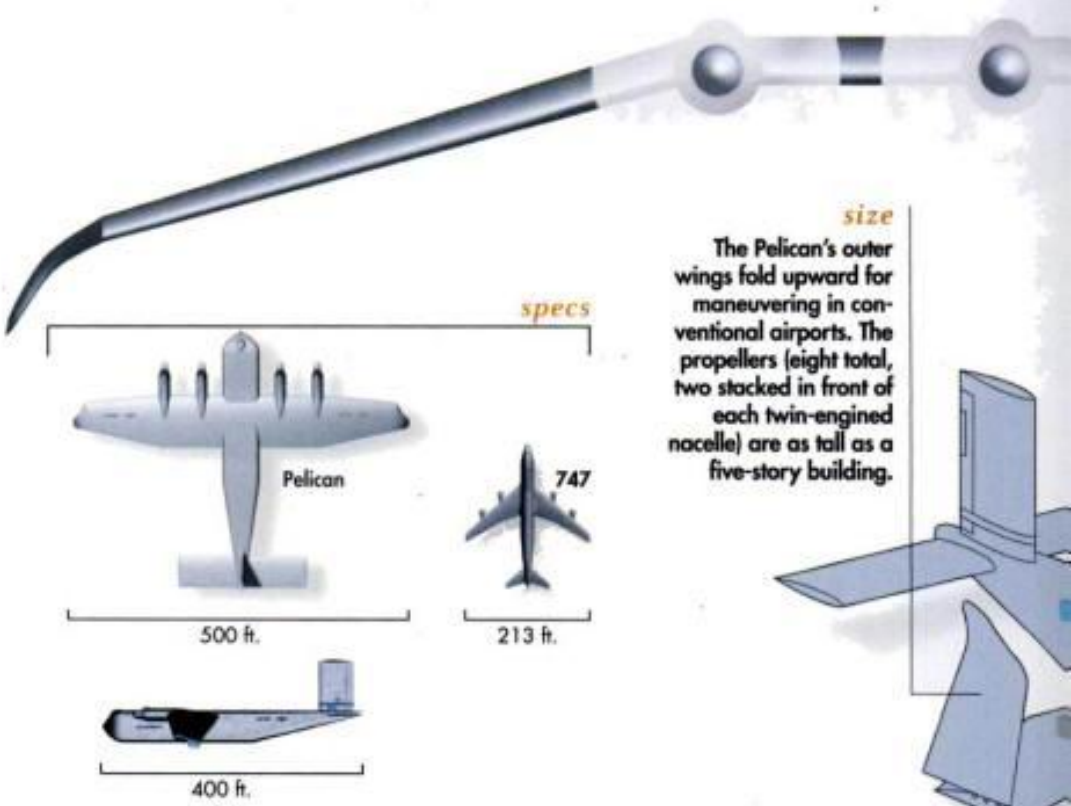
In early 2000, Skorupa, by then at Boeing, took the matter to Blaine Rawdon, a veteran Phantom Works designer who began focusing on the problem with engineer Zachary Hoisington. They knew that the Army was considering airships and airship-airplane hybrids designed to carry multimillion-pound payloads. Rawdon broadened Skorupa's question and looked at a wide range of solutions to the Army's problem, from a new generation of faster small commercial ships to airships to a large, conventional jet airplane, like a quadruple-size C-5. The value of speed always caused airplanes to come out ahead of airships and even the fastest marine vessels, but expanding aircraft to multimillion-pound payloads is not easy and would likely cost more than even the Pentagon can afford.

But ekranoplans, a specific type of WIG with short wings and jet boost for takeoff, seemed to offer some potential—as well as dramatically lower costs, if the concept could be made

WIG idea

PELICAN

IF BUILT, the Pelican will be the largest aircraft ever flown, weighing 3.2 million pounds and able to carry 2.8 million more. The C-5 Galaxy, the largest cargo lifter in the U.S. fleet, weighs at most 769,000 pounds at takeoff. Ten Pelicans could carry the same cargo as a single Navy LMSR (large, medium-speed, roll-on/roll-off) ship, but could cover in one day the distance the ship takes two weeks to travel.



size

The Pelican's outer wings fold upward for maneuvering in conventional airports. The propellers (eight total, two stacked in front of each twin-engined nacelle) are as tall as a five-story building.

Материал, защищенный авторским правом

feasible. WIG aircraft had attracted an enormous amount of U.S. interest after the breakup of the Soviet Union, and in 1993 the Defense Advanced Research Projects Agency looked into what the Russians had done. Boeing's studies confirmed DARPA's conclusion, as well as that of several Russians, that only a very large ekranoplan made sense, but also that the Soviet vehicle that came close had several inherent problems, mostly relating to its enormous weight. The 500-ton prototype, KM, completed in 1966, had 10 jet engines, two in the tail and eight attached to the forward wing. The 10 engines gulped fuel, and the aircraft had to reach 210 mph before it lifted off the water. The reinforced hull—necessary to withstand the pounding of the waves—significantly increased weight and reduced payload. But despite these weaknesses, the Russian achievements were impressive, according to former DIA analyst Stephan Hooker, who was one of the people in the Green Room on that day in 1967. The plane had less drag than an airplane of the same size, and the Russians had solved many stability and control issues.

hail the ekranoplan

The Soviet Union's 10-engine, 500-ton Caspian Monster prototype was handicapped by the heavy reinforced hull it needed to withstand the pounding waves.

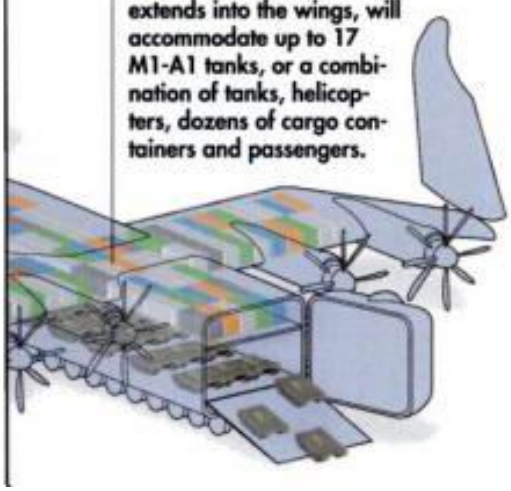
But the Soviet Navy's commanders were never enthusiastic about the program. Though the Central Hydrofoil Design Bureau, which constructed the prototype, built two more large ekranoplans—a 140-ton amphibious landing craft and a 400-ton vehicle armed with six anti-ship missiles—the Navy was already building large hovercraft for amphibious assaults and had bombers to strike NATO warships. Plus, the ekranoplans lacked the range to be useful as transports. The Navy accepted five out of a planned fleet of 140 and used them for trials, but none ever became operational.

Aware of this long, painful history and the many inherent challenges of WIG aircraft, Boeing engineers have revived the concept, with a key twist. The craft they're designing is a cross between a land-based airplane and a Soviet WIG. It exploits the WIG effect, but it can fly like an airplane over terrain and land at an airport. It doesn't need the ekranoplan's thick, heavy boat hull, or extra power to haul itself out of the water. It has become the Pelican, sharing its broad, drooped wings with the birds that swoop over California's coastline.

The Pelican, as currently envisioned, will be capable of flying at the same speed and height—300 mph, up to 20,000 feet—as most other airplanes powered by turboprops (jet engines geared to propellers, which, at Pelican's speed, are more efficient than standard jet engines). The difference is that it will cover significantly greater ranges while hugging the water's surface and taking advantage of the ground effect. There are two elements to the phenomenon. A wing lifts an airplane because the pressure beneath it is higher than the pressure above it—a result of the wing's shape and forward movement. At the lateral tip of the wing, the high-pressure air underneath flows around to the upper surface. This creates a vortex, a rotating airflow that robs the wing of lift. But if the aircraft is flying very close to the surface, there is no room for the vortex to develop properly and it becomes weaker. The sec-

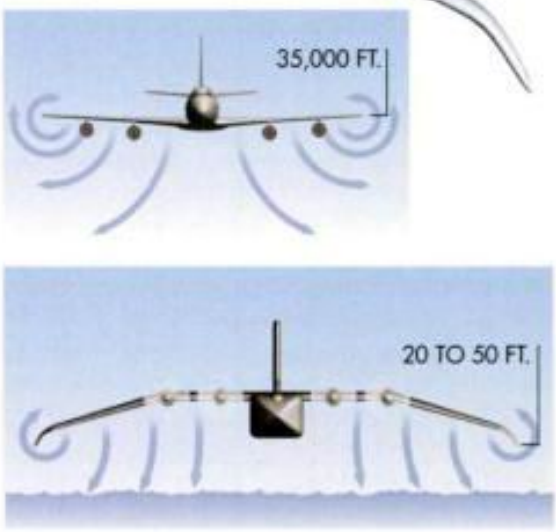
cargo capacity

A two-deck, 29,000-sq.-ft. cargo compartment, which extends into the wings, will accommodate up to 17 M1-A1 tanks, or a combination of tanks, helicopters, dozens of cargo containers and passengers.



how it works

The wing-in-ground effect prevents the wing from creating lift-robbing vortexes—since at extremely low altitude there's no room for them to form—and generates a cushion of air beneath the aircraft. The effect is stronger the closer the craft gets to the surface of the water. The Pelican would routinely operate at only 20 to 50 feet, altitudes at which it would burn half as much fuel as an airplane at high altitude.



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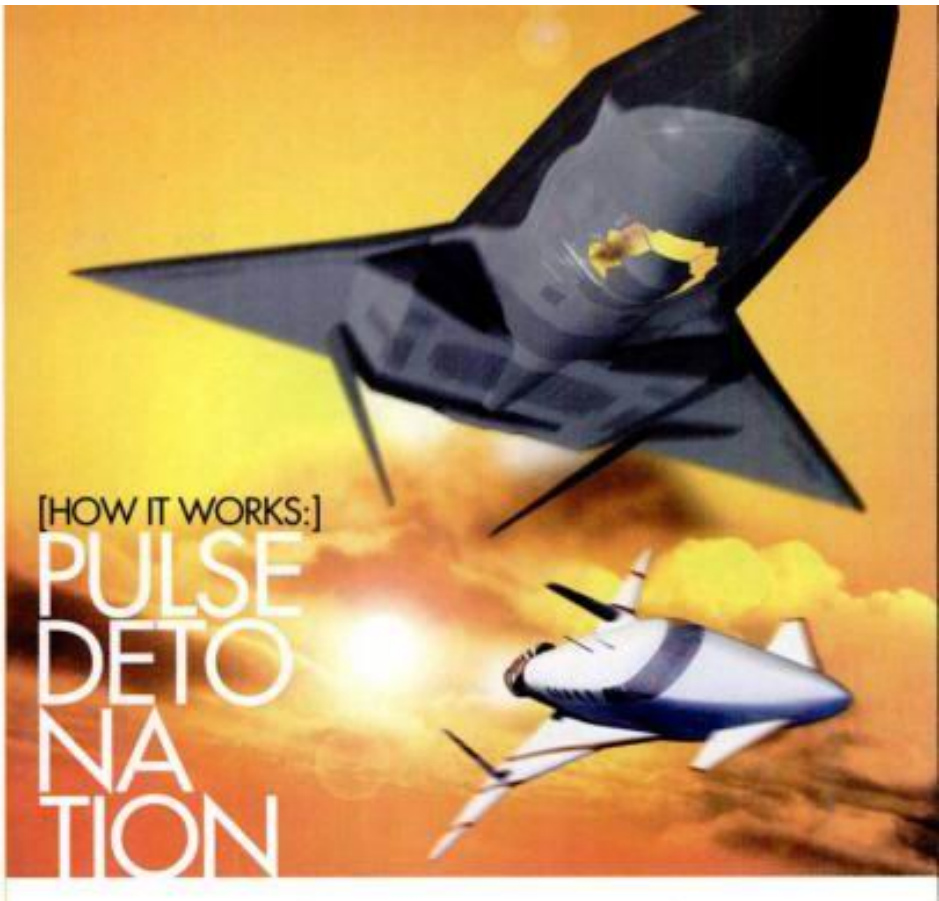
DRIVING FORCE **Pratt & Whitney's Gary Lidstone and Tom Bussing (opposite) think their pulse-detonation engine (testing version, above and below) will take off first.**

JOHN B. CARNETT; ILLUSTRATIONS BY STEPHEN ROUNTREE

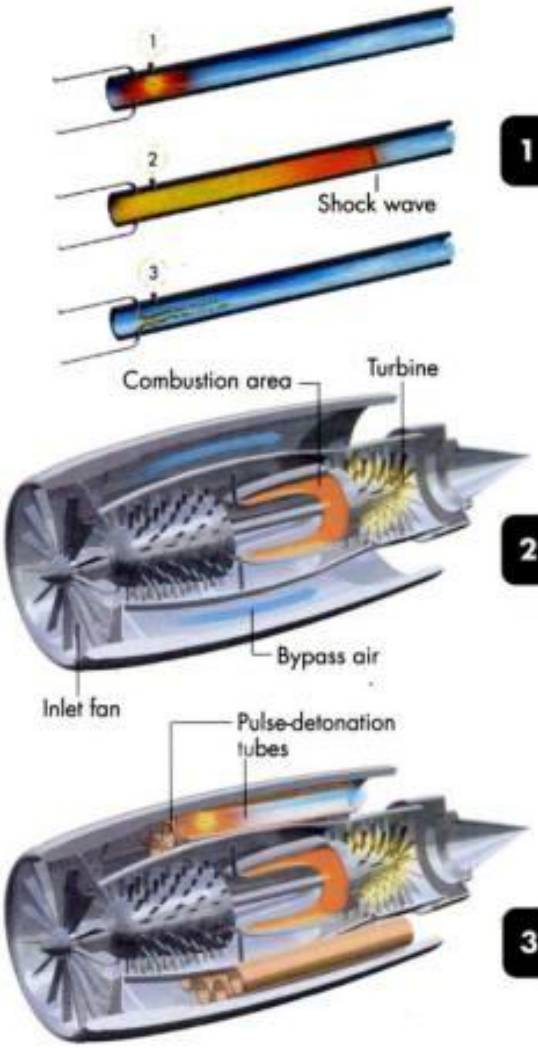


[HOW IT WORKS:] PULSE DETONATION

1 Pure PDE. Pulse-detonation engines use a more efficient combustion process, a detonation wave, to produce power. In a pure PDE, a spark ignites a tube filled with an air-fuel mixture (1). The explosion travels supersonically down the tube (2), blowing exhaust gases out the end and sucking more air and fuel inside (3).

2 Conventional turbofan. Jet engines produce power in two ways: A central combustion area creates a large amount of thrust but isn't efficient for long trips. For that, a turbine powers a fan, which blows air around the combustion chamber and out the back. The fan is efficient at subsonic speeds, but is unsuitable for long supersonic flights.

3 Hybrid PDE. A hybrid turbofan-PDE would combine both systems: The central core engine would still turn the large fan in front, but the bypass air would flow into a ring of PDEs. This system would produce significantly more thrust without requiring additional fuel.



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What's New

EDITED BY SUZANNE KANTRA KIRSCHNER WITH JENNY EVERETT

concepts in aviation

HOW ABOUT AN URBAN AERIAL UTILITY VEHICLE?

LATEST AIR-CAR DESIGN TACTIC AIMS AT COMMERCIAL APPLICATIONS.

In the race to build a so-called personal flying machine, few developers have got much past the tethered-hop stage, with promises of one in every garage sometime soon. Generations of hopeful flyers have died waiting. But Israel's Urban Aeronautics at least addresses a key point: A machine like the X-Hawk concept shown here (which the company recently released, saying it's the design they'll build) has less chance of serving your average frustrated commuter's needs than of playing a utility role in commercial and government transport. Projected uses include urban rescue, repair and patrol. The ducted fans mean the machine can safely approach tight areas where helicopters can't go—for example, as the company's literature ominously notes, up against "a high-rise building in New York City." Urban Aeronautics claims it is fast-tracked to actual flight testing because it will build X-Hawk around already-FAA-approved engines and rotors, and says it has received a patent. If that doesn't fly, there's always the military: The company, with a retired commander of the Israeli Air Force on its board, says it's working on a bigger TurboHawk design. *www.urbanaero.com*

inside: YOUR HUMANOID IS COMING 14 HOT HOME OFFICE SETUPS 18

ILLUSTRATION BY GARRY MARSHALL

Материал, защищенный авторским правом

month. But the capabilities of today's AUVs are nothing compared to what Bellingham and other sub designers expect to create in the next few years. The AUVs that will be the vital eyes and ears of underwater observatories will be able to deviate from their instructions to react to ambient conditions and communicate with one another.

On this day, Bellingham's latest AUV, named Dorado—a torpedo-shaped 17-foot by 21-inch vehicle—is sprawled in the lab, its upper panels removed to reveal computers and sensors in pressure-proof aluminum, glass and titanium housings. Should it go astray, it bears a painted notice: "Unarmed oceanographic equipment. Reward. If found call ..." It possesses 10 to 15 pounds of positive buoyancy; if disabled underwater, it will rise to the surface.

Dorado's science payload includes sonar to measure Arctic ice depths and sensors that, by detecting nitrates, oxygen, the amount of suspended matter and other parameters, identify how the properties of ocean water vary depending on the location, time of year and other factors. A conductivity-temperature-depth (CTD) instrument provides data necessary to calculate salinity and density, currents and sound velocity. Not long ago, CTDs came in packages that were about as big as an oceanographer and were lowered on cables from ships. Now they fit inside a small compartment inside Dorado.

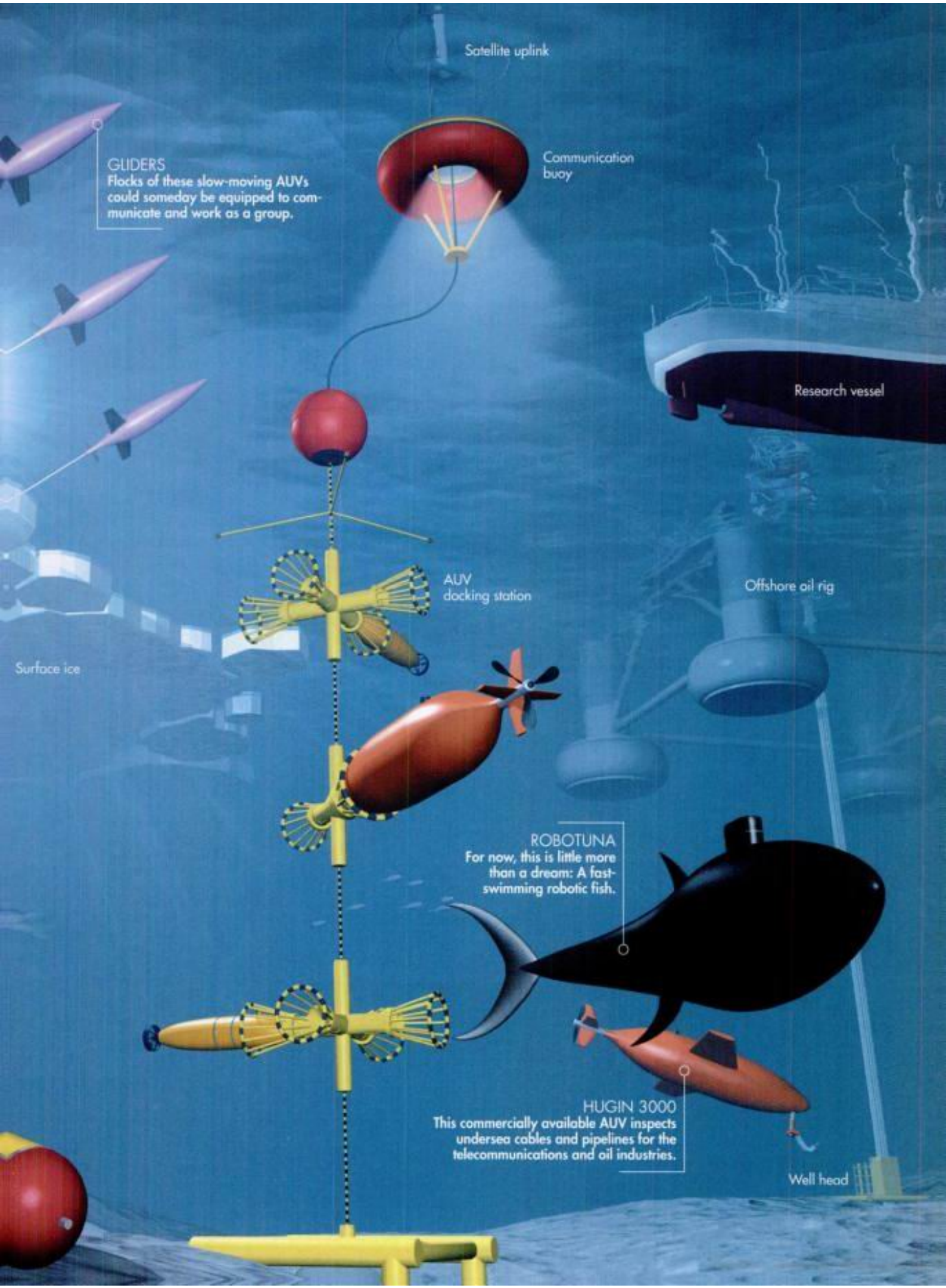
Shrinking instrumentation is one of the advances that's shaping the future of AUVs. In another lab downstairs is a device that can trap, pulverize and perform on-the-spot DNA analysis on selected microorganisms, separating the toxic creatures from their harmless look-alike companions. Nicknamed Darlene, the prototype resembles a life-size Picasso sculpture of metal framing, carousels, wires, vials, pulleys and belts. Within the next few years, Darlene will be downsized to fit into an AUV and conduct complicated biological sampling as the sub cuts through a plankton cloud or toxic algae bloom.

The Dorado—which on a future mission will fire sonobuoy probes into the underside of the Arctic ice sheet, leaving what Bellingham calls a bread-crumb trail—can swim at 3 knots for 12 hours and dive almost 3 miles down. For now, Bellingham and his crew hope to expand the amount of time their AUVs can remain at sea to about 20 hours by improving battery efficiency, but they are also testing a fuel-cell-driven version that could embark on a 260-hour jaunt.

THE DORADO IS ONE OF A CLASS OF AUVS KNOWN AS SWIMmers because they are fitted with huge batteries that power propellers. Swimmers can travel moderate distances and carry sizeable payloads. Another more recently introduced type of AUV, the glider, uses shifts in its buoyancy and center of gravity to dive and rise. Gliders tend to be smaller than swimmers and be focused on specific, limited tasks. They move slowly—about 0.5 mph—but they have great endurance.

A typical glider is the University of Washington's Seaglider, a needle-nosed vehicle about 6 feet long and 114 pounds, with stumpy fixed wings and a fixed tail. An electric motor moves the battery pack—and the Seaglider's center of gravity—fore and aft, to control the pitch of the nose. Roll control, which allows the Seaglider to bank like an airplane, comes from shifting the batteries from side to side. To move up and down through the water column, Seaglider adjusts how much oil

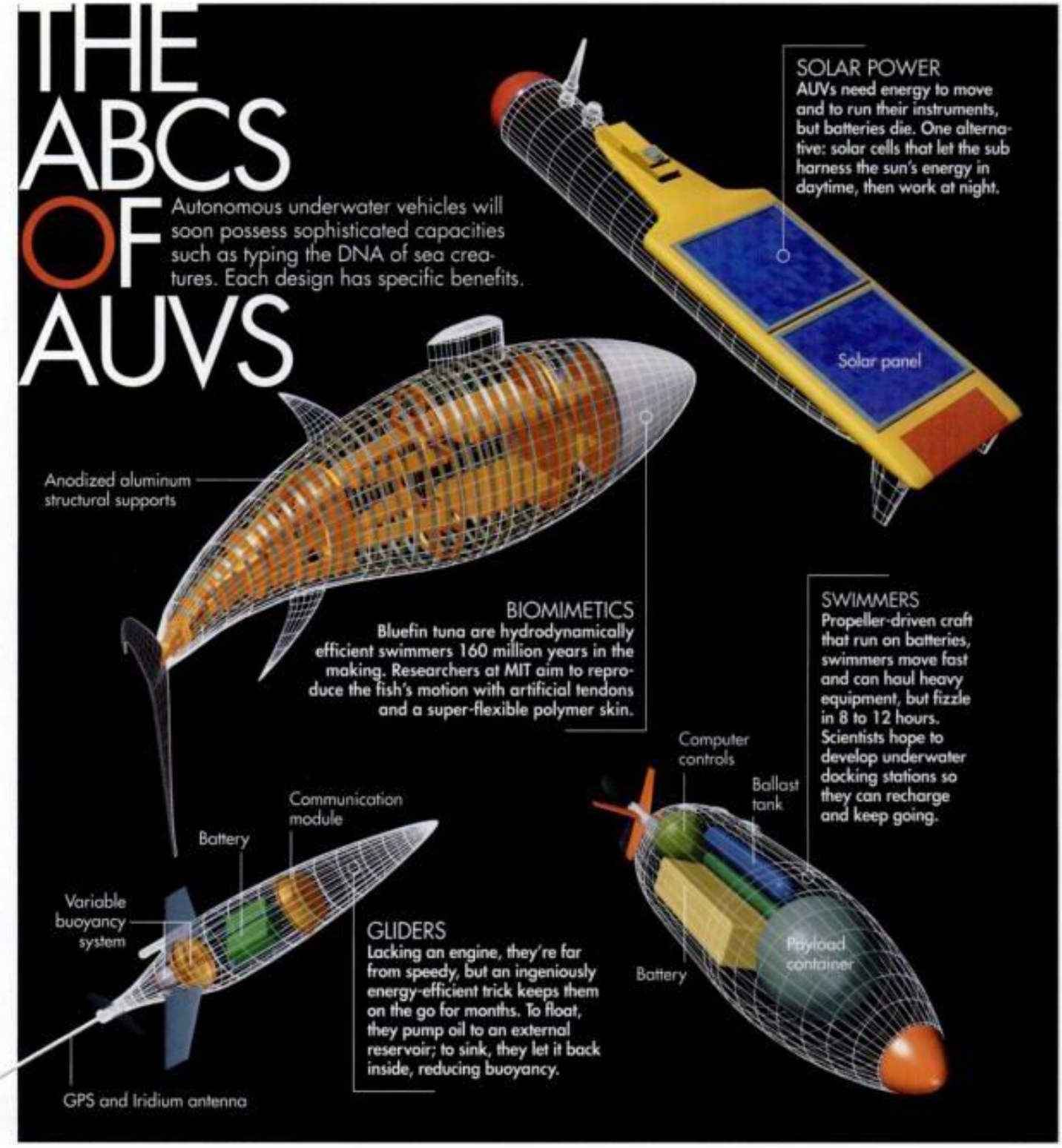
Eavesdrop on a conversation with one of the most visionary developers of autonomous subs at **www.popsci.com/exclusive**


Satellite uplink
GLIDERS
Flocks of these slow-moving AUVs could someday be equipped to communicate and work as a group.
Communication buoy
Research vessel
AUV docking station
Offshore oil rig
Surface ice
ROBOTUNA
For now, this is little more than a dream: A fast-swimming robotic fish.
HUGIN 3000
This commercially available AUV inspects undersea cables and pipelines for the telecommunications and oil industries.
Well head

it holds in an internal reservoir. To rise, the glider pumps oil into an external repository, increasing its buoyancy; when Seaglider is ready to sink, it lets the oil back in again.

After each dive, the Seaglider comes to the surface, then dips its nose underwater, raising its trailing antenna into the air to determine its GPS location, upload its data and download any new instructions via the Iridium satellite network. The Seaglider can plumb to depths of more than 3,000 feet and is designed to stay out for months at a time, repeating its pattern of dive, stop, ascend, surface, dive, stop, ascend, surface in a ceaseless slow-motion ballet. Meanwhile, AUV researchers are experimenting with other methods to power gliders. Engineers at the Autonomous Undersea Systems Institute in Lee, New Hampshire, for example, are developing AUV-appropriate solar panels; by periodically rising to the surface to bask in the sun while uploading their data, solar-powered gliders would be able to stay out on an environmental reconnaissance mission for a year or more.

TO PROGRAM AN AUV'S ASSIGNMENTS, OPERATORS WRITE A mission script, which is a computer program. Its list of tasks is precise: "Profile the water column. Don't run shallower than 10 feet. Cycle between 15°C and 7°C seawater. If you detect a cloud of plankton, sample it. Then go down to the seafloor, follow it for 45 minutes, look for biological life. Travel upward 500 feet, search for canyons and crevasses." After that



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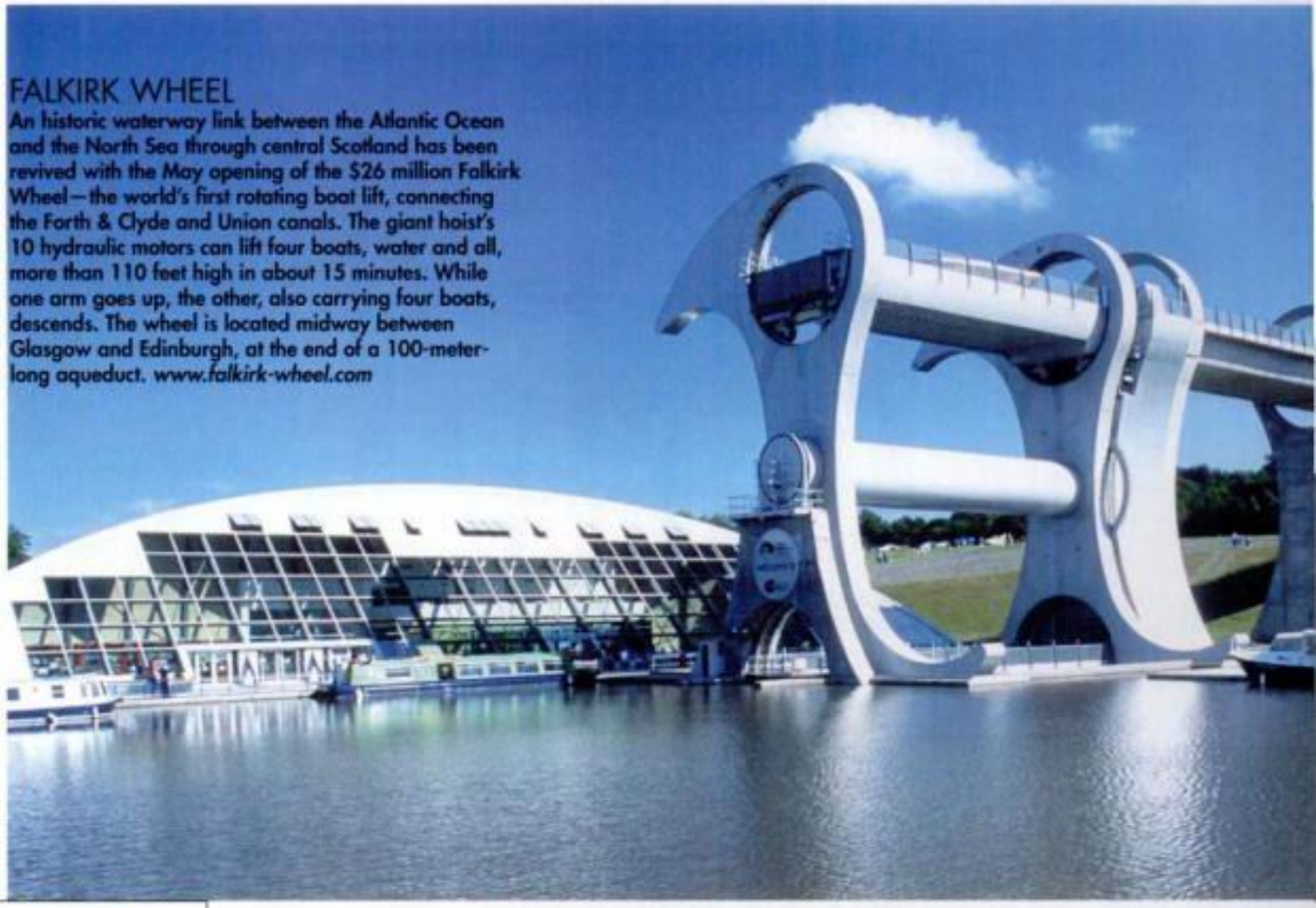
GENERAL TECH

This category presents a grab-bag of technologies but is no less compelling for that. Breathtaking ingenuity is the chief criterion for winning. Take the spectacular Falkirk Wheel, below. It's the first rotating boat lift not because the Scots beat the world to some technological breakthrough but because they were the first to put a gorgeous new spin on an old idea (boat lifts go way back). Take Dean Kamen's much-hyped Segway: Goofy. But the first time you ride it, you understand.



FALKIRK WHEEL

An historic waterway link between the Atlantic Ocean and the North Sea through central Scotland has been revived with the May opening of the $26 million Falkirk Wheel—the world's first rotating boat lift, connecting the Forth & Clyde and Union canals. The giant hoist's 10 hydraulic motors can lift four boats, water and all, more than 110 feet high in about 15 minutes. While one arm goes up, the other, also carrying four boats, descends. The wheel is located midway between Glasgow and Edinburgh, at the end of a 100-meter-long aqueduct. *www.falkirk-wheel.com*

15 YEARS OF... BIG ENGINEERING

1988 The $5.3 billion, 33-mile Seikan Rail Tunnel opened after 24 years of construction, marking the first time Japan's four main islands are linked by land-based transportation. It's still the world's longest rail tunnel.

***1989** The first stadium with a fully retractable roof, the Toronto SkyDome, opened. The 8-acre roof consists of panels that move on 76 steel wheels called "bogies." Each bogie is powered by a 10-horsepower electric motor. Opening time: 20 minutes. SkyDome has since spawned other retractable-roof stadiums.

1991 The biggest civil engineering project in U.S. history, the $15 billion Boston Central Artery/Tunnel project, or Big Dig, began. The most challenging part: burying parts of I-90 and I-93 under the Fort Point Channel. Just one-tenth of a mile long but costing $1.5 billion, the crossing is the most expensive highway project per mile in the world. The Big Dig will be completed in 2004.

1994 Construction of the Chinese Three Gorges Dam, a 20-year, $24 billion effort to build the world's largest hydroelectric dam, began. Plan called for 575-foot-tall dam a mile across, generating 84 billion kilowatt-hours of power. Reservoir will stretch 350 miles upstream.

***1994** After seven years of construction, the Eurotunnel—better known as the Chunnel—opened, "connecting England with Europe for the first time since the Ice Age." It runs 31 miles, 23 of which are underwater. The average depth is 150 feet under the seabed. Digging was done with the world's largest boring machines. Seven million passengers now travel through the Chunnel annually. Though the Seikan Rail Tunnel is longer overall, Chunnel's underwater portion is the world's longest.

1988 1991 1994

[*Best of What's New Winner. **Best of What's New Grand Award Winner]

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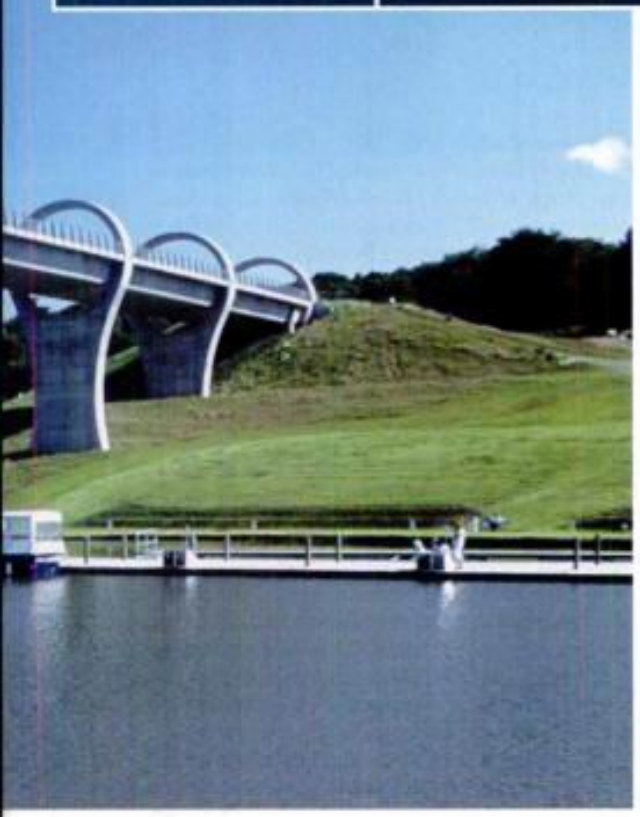
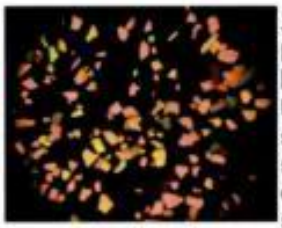
BEANTOWN'S NEW ENGINEERING SIGNATURE

In a city steeped in history, Boston's $86.4 million Leonard P. Zakim Bunker Hill Bridge is making history of its own. The widest cable-stayed bridge in the world, it carries 10 lanes of traffic over the Charles River. It's also the first U.S. hybrid bridge (part steel, part concrete) with an asymmetrical design. The 270-foot-tall bridge, which opened to foot traffic in May (cars in December), is part of Boston's massive Central Artery/Tunnel Project. *www.bigdig.com*



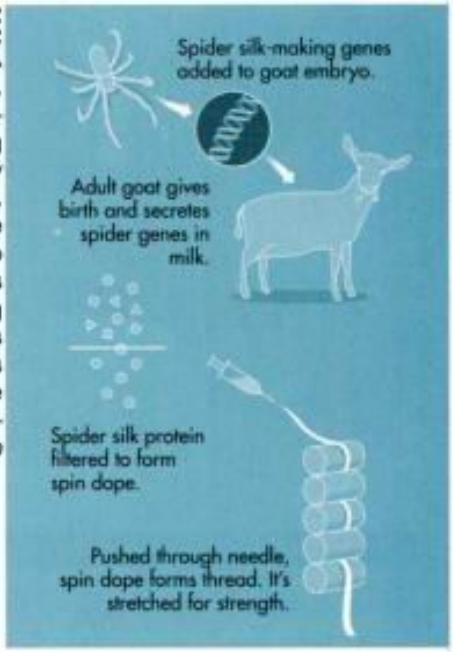


SMART DUST

Detecting chemical weapons isn't easy, but help is coming in a tiny package. Unveiled in March, "smart dust" is the smallest, most sophisticated chemical sensor ever created. A handful could sniff out thousands of biological and chemical substances at the same time and then be read with a laser akin to a grocery scanner. It might also help scientists monitor atmospheric pollutants. *www.ucsd.edu*

GOAT-MADE SPIDER SILK

Spider silk is ultrastrong, light, elastic and biodegradable—ideal for everything from surgical sutures to body armor. Unlike silkworms, though, spiders don't take well to animal husbandry. So scientists spliced their genes into goat DNA, producing goats that secrete silk proteins in their milk. BioSteel, as it's called, is the first man-made fiber with spider-silk properties. *www.nexiabiotech.com*



1996 At 1,483 feet, the Petronas Towers in Kuala Lumpur, Malaysia, became the tallest buildings in the world, surpassing Chicago's Sears Tower. Most notable design detail: a 192-foot, 1.65-million-pound sky-bridge connecting the two towers at the 41st floor, 558 feet above the ground. The tallest crown will pass to Taipei Financial Center in 2004.

1996

1998 After 12 years, the longest suspension bridge in the world, the $4.3 billion Akashi Kaikyo Bridge, opened in Japan, linking Shikoku and Honshu. At 6,570 feet, Akashi Kaikyo's center span is nearly 2,000 feet longer than Britain's Humber Estuary Bridge. Its 933-foot towers also make it the tallest bridge in the world. A network of trusses below the roadway enable the bridge to withstand hurricanes and 8.5-magnitude earthquakes. Akashi will lose its crown in 2010, when Italy's 10,890-foot Stretto di Messina Bridge, linking Sicily to the mainland, opens.

1998

1998 Hong Kong's new $20 billion airport opened. The project included a 21-mile railway, a six-lane expressway, two tunnels, two bridges, two islands and high-rise housing. Hong Kong International eliminated one of the most harrowing approaches in aviation: Aircraft flew so low that rumors circulated about snagged high-rise laundry lines.

2002 Reverse engineering on a massive scale: Cleanup of the World Trade Center site ended in June, three months early and at a cost of about $750 million—less than a tenth the cost originally predicted. 1.8 million tons of rubble were hauled from the 16-acre site to landfills on Staten Island and in New Jersey. Much of the Trade Center's steel will be recycled.

2002

CLOCKWISE FROM TOP LEFT: COURTESY OF BRITISH WATERWAYS SCOTLAND; JASON LEE; MICHAEL SCOPIAK/CASEY KEITY; HONSHU-SHIKOKU BRID; JASON LEE; DAVID PORTNOY; COURTESY OF PAOLO PASTORE

into the abyss

A tough new diving suit lets Navy divers go to depths never before possible. By Frank Vizard

PHOTOGRAPHY
JOHN B. CARNETT

DEEP DIVER
The first Hardsuit 2000 maneuvers underwater during a test.

This isn't good. You're way down deep in the sea, trapped in a damaged submarine. You can't stop thinking about the 118 Russian sailors who perished in August 2000 aboard the ill-fated *Kursk*. Or the fact that in the history of undersea vessels, only one sunken submarine has been successfully rescued. In 1939. And, in fact, they didn't even save the entire crew of the USS

Ready to Rescue

In the event of a submarine disaster, a diver wearing the U.S. Navy's new Hardsuit 2000 would be first on the scene. The atmospheric diving suit is certified to depths of 2,000 feet, but tests indicate that 3,000 feet is within reach.

HELMET ARRAY
A dive supervisor topside can see what the diver sees via the video camera to the right of the diver's helmet. On his left is a sonar array for pinging a hidden target.

THRUSTERS
When the diver needs to get moving, two side thrusters provide the locomotion. Pitch and direction are controlled by footpads inside the suit.

Squalus, you recall with an ominous sense of grim foreboding.

Suddenly, unexpectedly, thankfully, your dismal reverie is broken by the sound of footsteps outside the hull. It's the first rescuer, operating at a depth never before possible, clad in a dive suit that, with its huge bubble of a helmet, wouldn't look out of place in outer space.

That's the welcome prospect that will greet submariners in peril starting early next year, when the U.S. Navy's new dive suit, the Hardsuit 2000, is scheduled to be introduced. Currently finishing sea trials with the Navy off the coast of San Diego, the suit is certified to operate at a depth of 2,000 feet, some 800 feet lower than previous models could go. The Hardsuit 2000 has gone even deeper in test dives—as far as 3,000 feet below the ocean surface.

"This is a big leap for the extension of man's presence under the water," says Mike Holmes, the Navy's program manager for the project.

The Hardsuit 2000 is a one-atmosphere suit, meaning the operator inside its tough shell breathes

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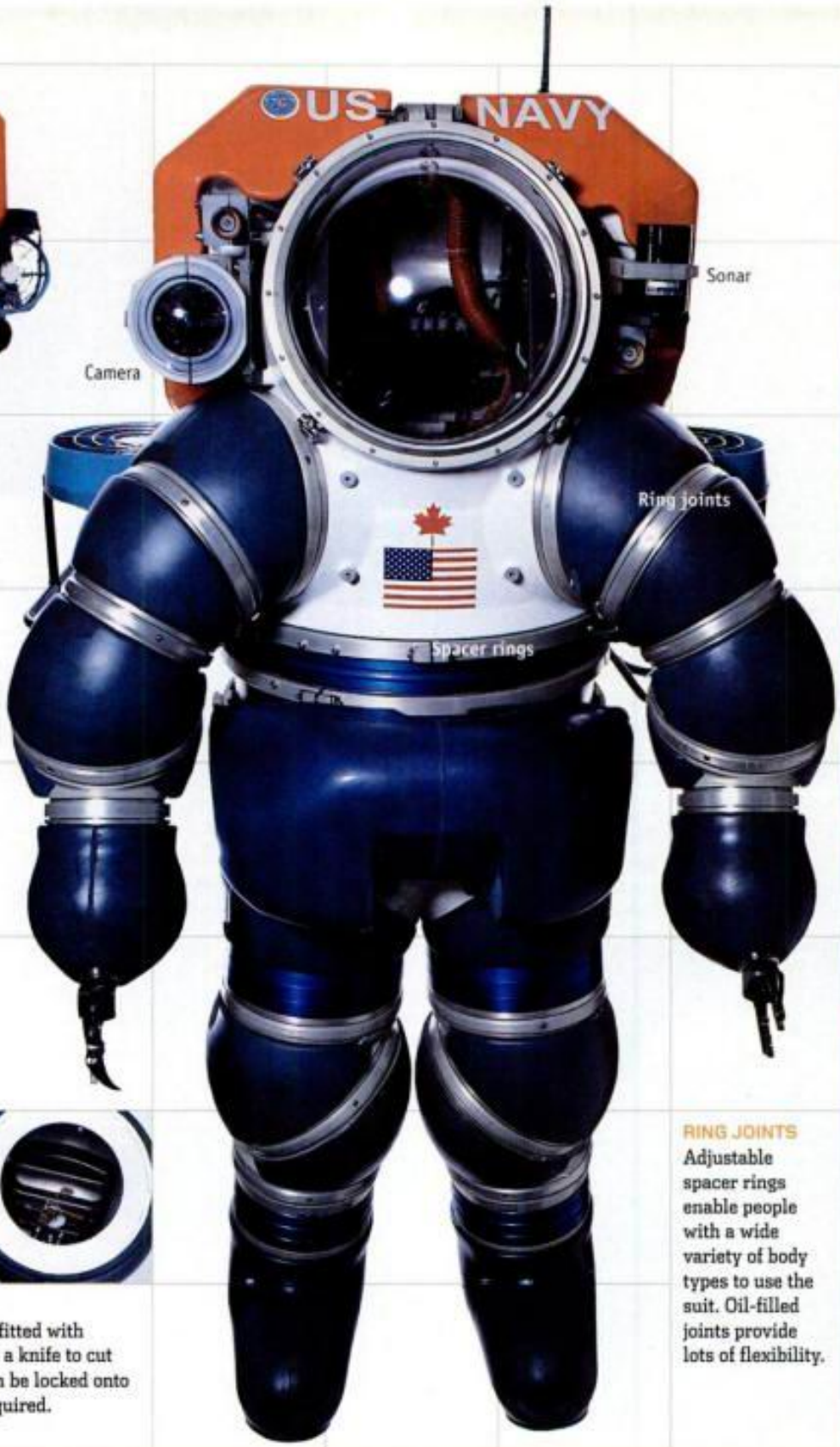

OXYGEN TANK
Divers can stay underwater for between 8 and 10 hours, depending upon how they regulate their oxygen supply.

HAND PODS
Hand pods can be outfitted with various tools, such as a knife to cut a line. A hand pod can be locked onto an object (inset) if required.

RING JOINTS
Adjustable spacer rings enable people with a wide variety of body types to use the suit. Oil-filled joints provide lots of flexibility.

Taking the Plunge

How deep can we go alone? Here's the lowdown.

- **130 ft.** Recreational scuba diver
- **400 ft.** Mark V suit
- **532 ft.** Free dive
- **833 ft.** Scuba dive with mixed gases
- **984 ft.** Bottlenose dolphin
- **1,200 ft.** Commercial diver
- **2,000 ft.** Hardsuit 2000 (rated)
- **3,000 ft.** Hardsuit 2000 (tested)

the same air mixture as someone on land. Thus there are no concerns about potentially lethal decompression sickness, a.k.a. the bends. And despite its 1,700-pound weight, the suit is highly maneuverable once it's in the water, thanks to a pair of side-mounted thrusters. "You can spin on a dime, hover against the current, or lay on your back," says Holmes. "Good pilots can even roll over."

Foot pedals inside the suit control the thrusters. Other key features include hand pods for grasping tools, and oil-filled floating joints for greater arm and leg flexibility. Attached to the helmet is a sonar device, as well as a video camera that enables a supervisor aboard ship to monitor the diver's movements. Adjustable spacer rings on the suit's arms, legs, and waist enable people of varying heights and weights to fit comfortably inside.

During a rescue mission, divers wearing the new suit will be attached to a frame assembly and lowered to within 30 feet of the targeted depth. They will then untether themselves, make their way to the

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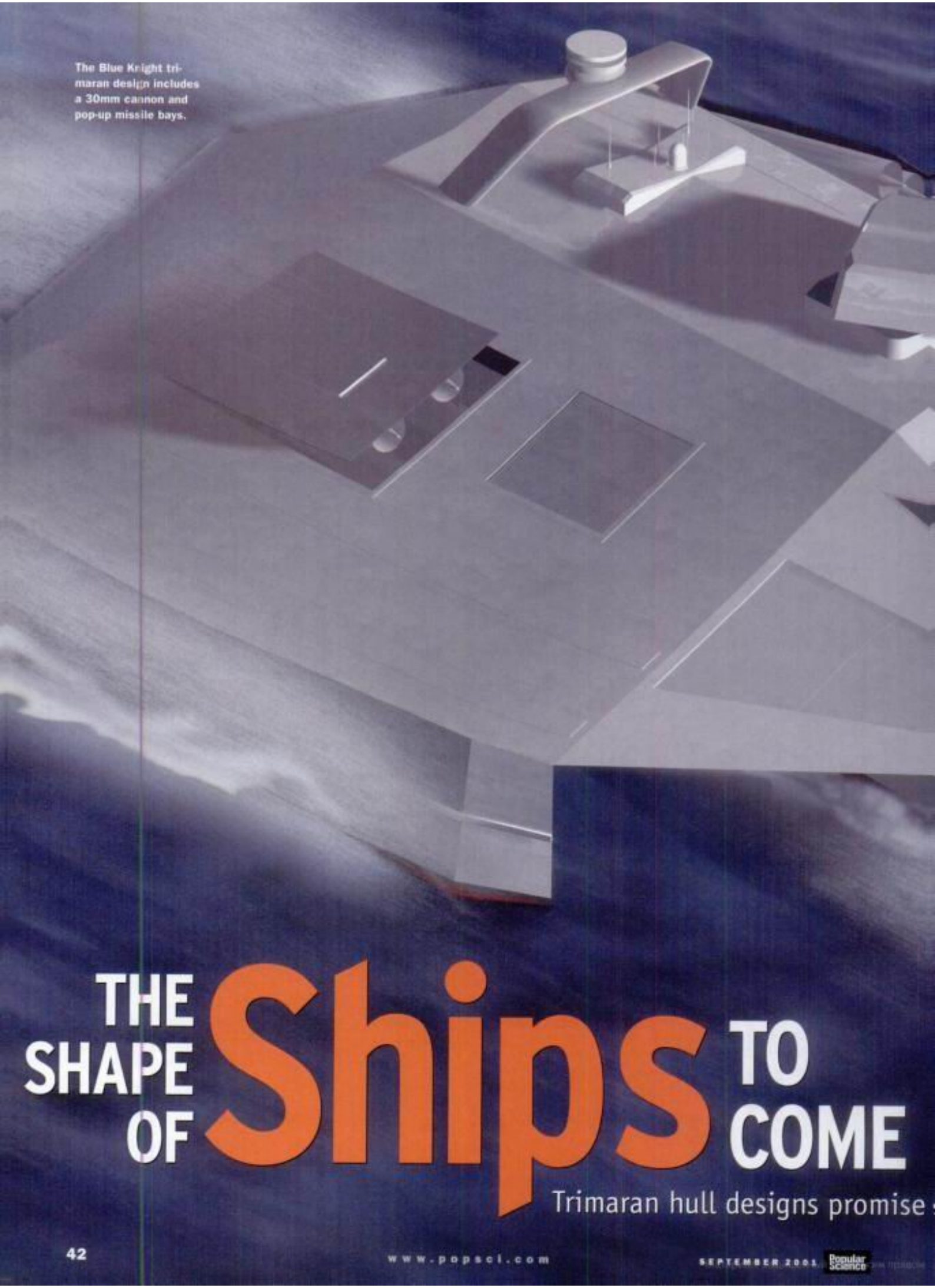
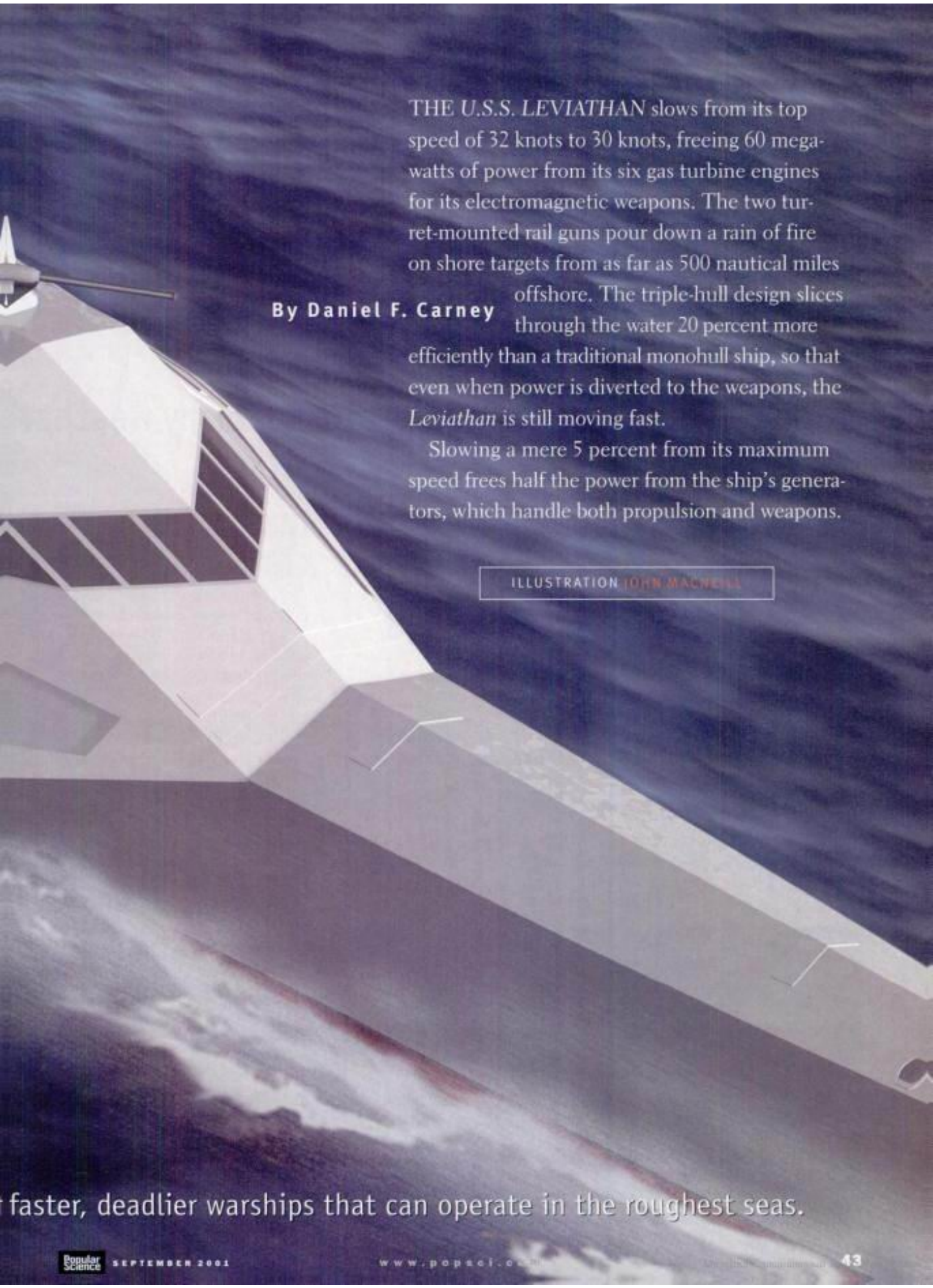


The Blue Knight trimaran design includes a 30mm cannon and pop-up missile bays.

THE SHAPE OF Ships TO COME

Trimaran hull designs promise



THE *U.S.S. LEVIATHAN* slows from its top speed of 32 knots to 30 knots, freeing 60 megawatts of power from its six gas turbine engines for its electromagnetic weapons. The two turret-mounted rail guns pour down a rain of fire on shore targets from as far as 500 nautical miles offshore. The triple-hull design slices through the water 20 percent more efficiently than a traditional monohull ship, so that even when power is diverted to the weapons, the *Leviathan* is still moving fast.

By Daniel F. Carney

Slowing a mere 5 percent from its maximum speed frees half the power from the ship's generators, which handle both propulsion and weapons.

ILLUSTRATION JOHN MACNEILL

faster, deadlier warships that can operate in the roughest seas.

Blue Knight Patrol Boat

MAXIMUM SPEED 47.7 knots
POWER Diesel waterjet
LENGTH 132.6 feet
BEAM 56.0 feet
WEIGHT 129 tons
ARMS 30mm cannon, pop-up missile system
OPERATING SEA STATE* 3
SPECIAL FEATURE Manned and unmanned versions

*Sea roughness (1 to 5, from calmest to roughest)

Trimaran warships could operate in stormy weather

The ship carries more than 12,240 projectiles for its rail guns, which use electromagnetism to accelerate the rounds to a speed of Mach 10. Despite the guns' smaller size, this velocity gives them the explosive impact of shells from the 16-inch guns on an Iowa-class battleship.

Trimaran warships are still at least a decade down the road, but the concept is under intense study by both the U.S. and British navies. Both sea forces are considering a wide variety of ship sizes, ranging from full-scale battleships to patrol boats. And while trimaran designs do have some drawbacks, a precursor called the *RV Triton* is already at sea testing the validity of the design in rough waters. Trimarans should be able to operate in stormy weather that would send most ships scurrying to a safe harbor.

The biggest, the 750-foot, 25,745-ton *Leviathan*, is a key component in the Navy's Sea Strike vision of future naval combat. "The concept requires 10 very large warships with rail guns, which require a lot of power," says Jeff Koleser, senior naval architect at the Naval Sea Systems Command. "They also would carry a lot of unmanned armed vehicles. The idea behind Sea Strike is to overwhelm any potential enemy with lots of firepower."

The stability afforded by the triple-hull design helps the gunners hit their targets more easily. Shelling would be the second stage of an assault, following an airborne attack that ensures that the *Leviathan* isn't at risk from the sky. The vessel's 121-foot-wide deck provides space for four helipads, so the crew can launch—and then recover—the ship's unmanned aerial vehicles to patrol and even attack targets should they appear.

"You can see why a trimaran might work for this kind of a mission," says Tom Cannon, naval architect and program manager for trimarans at Naval Sea Systems. "You are always going to get a power advantage over a conventional monohull. And the deck versatility really helps out with the unmanned vehicles and big guns."

The *Leviathan* is one of about 40 hypothetical future warships designed by naval architects at the Naval Sea Systems Command for testing in computer wargames to sort out which designs can be expected to work best. The trimaran hull design concepts range from the giant *Leviathan* to the

Frigate

MAXIMUM SPEED 30-plus knots
POWER Generators and fuel cells
LENGTH 528.2 feet
BEAM 78.1 feet
WEIGHT 5,630 tons
ARMS Missiles, medium-caliber gun, torpedoes
OPERATING SEA STATE 5
SPECIAL FEATURE Search and rescue, surveillance, and information warfare capabilities

Corvette

MAXIMUM SPEED 30-plus knots
POWER Electric generators and diesel engines
LENGTH 489.8 feet
BEAM 71.5 feet
WEIGHT 2,828 tons
ARMS Multiple missile launchers
OPERATING SEA STATE 5
SPECIAL FEATURE Advanced electronic warfare system, drug interdiction, and other law enforcement tasks

that would send most ships scurrying to a safe harbor.

diminutive *Blue Knight* patrol boat. Some midsize corvette and frigate designs should be useful to the Coast Guard and for export to U.S. allies. The triple-hull layout contributes to greater speed, lower fuel consumption, better stability, and improved maneuverability compared with monohull designs.

The *Leviathan*'s smooth-sided trimaran hull resembles a 19th-century ironclad more than a 21st-century ship, but the slab-sided appearance, along with the elimination of topside clutter such as railings and antennas, reduces the radar profile. The rear-sloping tumblehome bow design completes the ironclad look.

Surrounding the *Leviathan* is an escort of manned and unmanned vessels—all coordinated by a single, networked combat information center—that constantly sweep the area for any adversaries. Threats are spotted by unmanned sensor craft and are dispatched by other unmanned weapons ships. These unmanned vessels could be two variants of the *Blue Knight* trimaran, each outfitted for different tasks and controlled through a combination of radio and satellite communication systems.

But should a threat get past the *Leviathan*'s escort fleet, armored outriggers also provide some measure of protection for the main hull from incoming missiles and torpedoes. The six gas turbines that power the ship are distributed throughout the vessel, and power routing is flexible so that the *Leviathan* can maintain some power even if some of its engines are damaged. The hull has an inner liner, providing underwater explosion protection in case of a mine or torpedo strike.

Another distinctive feature are thrusters, or azipods, in the *Leviathan*'s outriggers that make the ship almost infinitely maneuverable. With the outboard thruster pods aimed in opposite directions, the ship could rotate in place. Such maneuverability is novel in a warship and might be most useful when engaged with a submarine, notes Capt. Bob Shields, a retired U.S. Navy missile cruiser skipper. "If you are in close with a sub, you would like to be maneuverable," he says. The outboard thrusters would also aid docking in less developed ports and would let the *Leviathan* dock in developed ports without depending on local tugs.

Leviathan

MAXIMUM SPEED 32 knots
POWER Electric and diesel. Azipods in side hulls
LENGTH 750.0 feet
BEAM 121.4 feet
WEIGHT 25,745 tons
ARMS Two rail guns, missiles, 80 unmanned aerial and underwater vehicles
OPERATING SEA STATE 5
SPECIAL FEATURE 12,240 rounds of ammo for rail guns

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SPACE

MMMM, SPACE CHIPS

Little spacecraft could hitch a ride on Earth's magnetic field to search for alien life

THE NEXT GENERATION of robotic space explorers could be smaller than a dime—and cost about that much, too. Mason Peck, an engineer at Cornell University, envisions thousands of miniature spacecraft drifting to different planets, powered only by Earth's magnetic field. Peck's novel magnetic-propulsion method recently earned him a $75,000 grant from NASA's Institute for Advanced Concepts to bring the idea closer to reality.

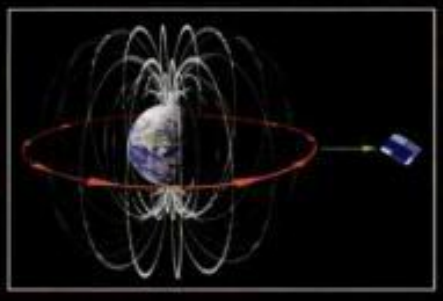
The system's biggest advantage is that it could shave millions of dollars off the typical NASA satellite launch, because it requires almost no rocket fuel once in orbit. Instead the chips use the Lorentz force, a physics phenomenon that acts on electrically charged particles moving in a magnetic field. In this case, the force would help the chips escape Earth's gravity and head for a distant planet. On arriving, the chips would rain down on the planet, analyze atmospheric or surface samples, and then signal to Earth if they found anything interesting—amino acids typical of cellular life, for example.

Peck and his team are currently testing Lorentz propulsion in the lab. If all goes well, the force could help launch full-size satellites, deliver bulk building materials to a moon base and, Peck's personal favorite, send a space-chip mission to Jupiter's moon Europa by 2030.—GREGORY MONE

FIRST-CLASS DELIVERY
Paper-thin and just a quarter of an inch per side, 25 space chips could fit on a stamp.

SENDING SPACE CHIPS TO EUROPA

1 Thousands of chips are packed into the nose of a rocket and launched into low orbit. Each chip's solar panel sends electrons to a capacitor, which pumps them through a long, trailing wire to electrically charge the chip.



2 The Lorentz force acts on the charged chip as it orbits [red] through Earth's magnetic field [gray] to produce a force [green] that nudges the space chips to higher altitudes.

3 After about a year, the Lorentz force will have imparted enough energy to free the spacecraft from Earth's gravity. Timed properly, Mason Peck says, the swarm will fly freely on a trajectory for Jupiter's moon Europa.

4 After a two- to four-year journey, simple thrusters adjust the chips' heading as they approach Europa. They are too small to burn up as they enter the atmosphere, and with several thousand en route, the mission will remain intact even if a few chips don't make it.

BOB SAULS/FRASSANITO

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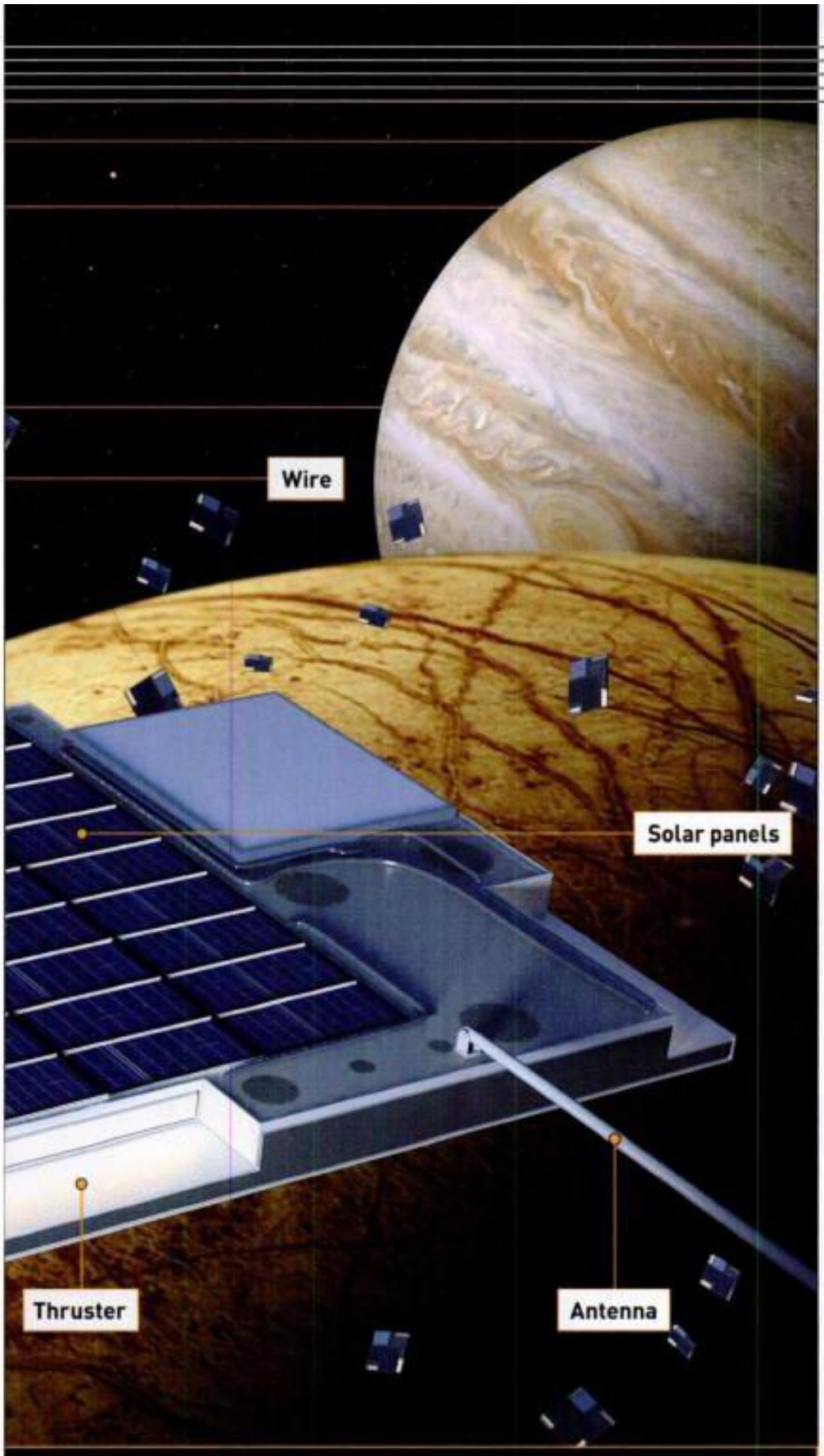

5 Chips collect molecules from the air or the moon's surface for analysis. Peck suggests a simple collection mechanism: Microparticles would stick to liquid on the chip's surface, which would be sucked inside the chip.

6 Each chip sends a basic, one-bit signal if it finds signs of life. Thousands of chips reporting similar findings could motivate NASA to fund a more comprehensive—and expensive—mission.

Last year, Beijing's Weather Modification Office announced plans to use a technique called cloud seeding, which attempts to induce precipitation by filling moisture-laden clouds with tiny particles of silver iodide. The particles, dispersed by plane or shot into the air from ground-based rockets, enable water vapor to condense and form raindrops.

Invented in 1946 and used all over the world, including the U.S., cloud seeding

China hopes forced rain will clean Beijing's bad air before the Olympics.

remains controversial, in part because it's so difficult to prove whether it actually works. Dan Breed, a scientist with the National Center for Atmospheric Research, says that even if the Chinese seed a series of rain clouds prior to the Games and precipitation then washes away the pollution, it doesn't constitute proof. The clouds might have rained anyway, without the particles.

Nor would a foolproof technique eliminate the element of chance, notes Bill Cotton, an atmospheric scientist at Colorado State University. Beijing will still need the right kind of clouds, and in the right place. "You can't make it rain if the conditions are not set for rain," echoes Streets.

Compounding the issue is a study Streets published last spring showing that 50 percent of the bad air in Beijing originates in the industrial provinces to the south, so even banning cars and inducing thunderstorms may not be enough to clean the air. "Even if Beijing shut down, you'd still get pollution," he says. "This is going to be the challenge for the Olympic Games."

Streets thinks officials will postpone events if the air is bad. But Kenneth A. Rahn, a visiting atmospheric chemist at Beijing's Tsinghua University, who is conducting a massive study of pollution in China, suggests another strategy, based on the fact that periodic shifts in weather patterns can carry clean, fresh air down from Mongolia in the north, clearing Beijing's skies. His advice: "Pray to the Mongolian weather gods."—GREGORY MONE

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5 MODEST PROPOSALS TO SAVE THE PLANET

The obvious first step in any environmental strategy is to stop mucking up the environment. If that doesn't work, we'll need to get creative

BY RENA MARIE PACELLA ILLUSTRATIONS BY GRAHAM MURDOCH

RE-ICE THE ARCTIC

Salty ice could keep ocean currents flowing

WHERE: NEAR GREENLAND COST: $50 BILLION

THE PROBLEM: Arctic ice is melting, diluting the salty seas with freshwater and, many suspect, weakening the ocean currents that help regulate the global climate by transporting heat around the globe. If these currents were to shut down, the consequences would be unpredictable and dire: immense loss of marine life and fisheries; a reduction in the ability of the ocean to remove greenhouse gases from the atmosphere; and, some scientists speculate, drastic cooling of Northern Europe.

THE FIX: Make more Arctic ice, and make it salty. Under normal conditions, warm-water currents like the Gulf Stream carry heat from the tropics to Europe. After a current releases its heat, the water sinks (cold water is more dense than warm; salty more dense than fresh) and flows back to the equatorial regions along the ocean floor. This sinking is the engine that powers global currents. But in one apocalyptic scenario, melted Arctic ice dilutes the water in the North Atlantic to the point where the tropics-bound current isn't dense enough to sink. The heat-carrying currents skid to a halt, and Europe enters a new ice age.

Industrial engineer Peter Flynn of

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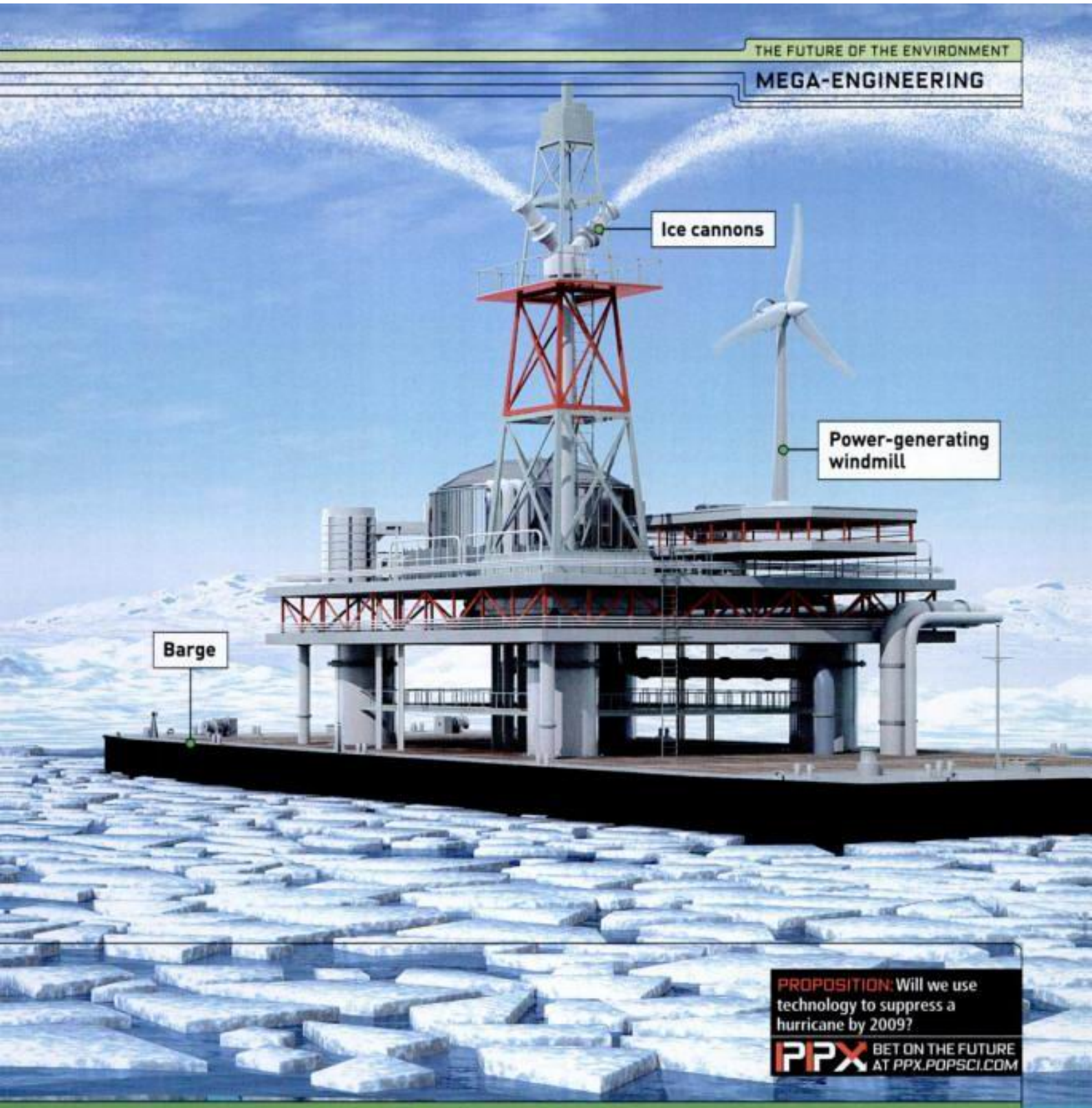

PROPOSITION: Will we use technology to suppress a hurricane by 2009?

PPX BET ON THE FUTURE AT PPX.POPSCI.COM

the University of Alberta proposes a bold way to boost currents if they begin to slacken: Tow 8,000 ice-making barges to the Arctic, and make a salty ice cube the size of New Mexico. In this plan, the barges would arrive off the coast of Greenland in the fall. As winter set in and air temperatures fell below 14°F, wind-powered water pumps on the barges would shower salty seawater on top of the existing ice pack, creating new layers of extremely salty ice.

Come spring, the barges would boost the currents by spraying more water onto the newly formed saline ice pack. As it melted, the cold, dense, salty water would sink into the deep ocean. The result: a 6 percent increase in down-welling currents, enough to keep the system moving along.

NEXT STEPS: Flynn does not advocate implementing this solution now —only if the slowdown reaches a critical threshold (what that threshold is and when it may occur is still in question) and only if all else fails. It's not a plan B, he says; it's a plan D. Instead, a better course of action would be to ensure that the down-welling currents and ocean conveyor belt not be suppressed in the first place.

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By Mariette DiChristina

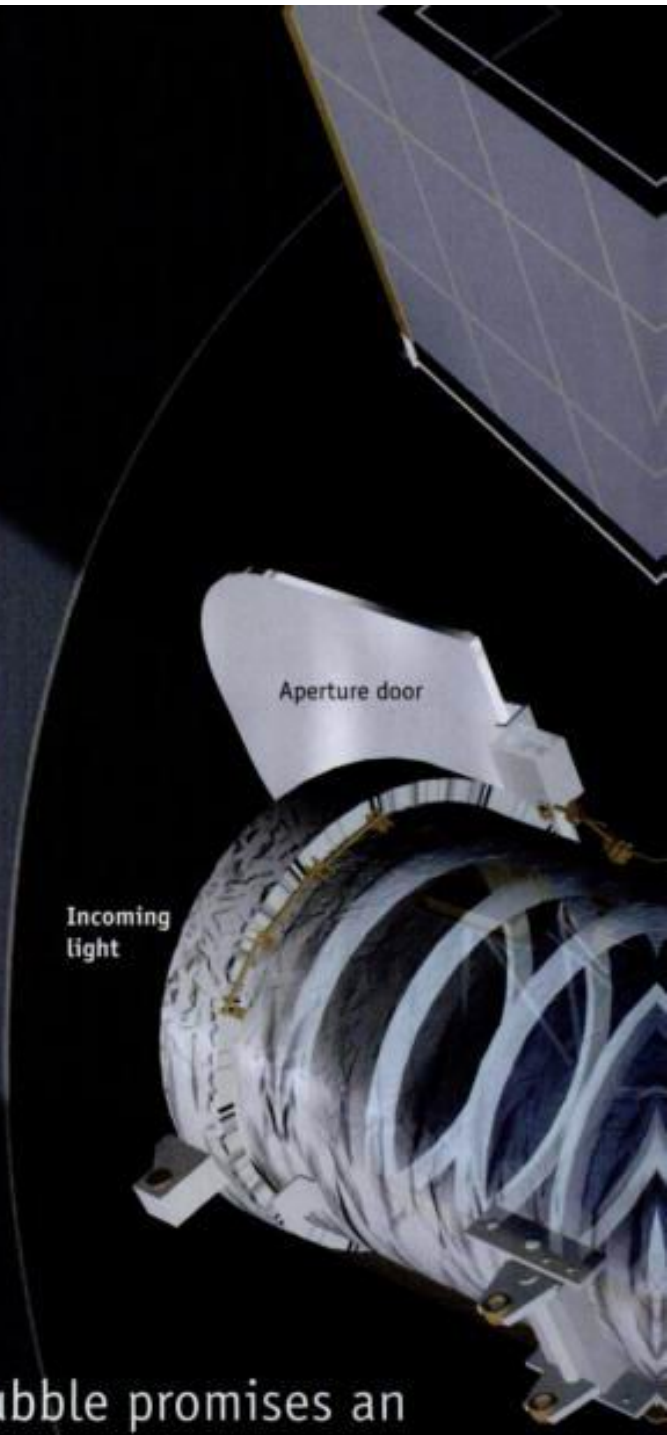
THINK OF IT AS A 60,000-mile tune-up: If all goes as planned, in mid-October the Hubble Space Telescope will be visited by spacewalking service mechanics—astronauts to you and me—for the third time in its nine-year life. Their mission? To replace more than a dozen aging or inoperable components.

"It's like when you bring your car into a garage for the mechanic to fix it," says John Campbell, associate director for the Hubble Space Telescope at Goddard Space Flight Center in Greenbelt, Maryland. "You hope not to come back for some number of years. If the mission is successful, all of the telescope's infrastructure will be upgraded."

Launched in April 1990, Hubble was designed to be serviced in orbit, and has undergone two successful upgrade and repair missions. The first, in 1993, corrected the telescope's notoriously nearsighted primary mirror with "eyeglasses," and added a new camera and other enhancements. In 1997, the second mission included an instrument that, for the first time, stretched Hubble's vision into the infrared portion of the electromagnetic spectrum; previously, the telescope was able to see only in the shorter visible and ultraviolet ranges.

With a long list of upgrades on the docket for the third mission—and the complexities of scheduling shuttle flights around the construction of the International Space Station—NASA decided to split Hubble's tune-up into two parts. "The first part is more of an engineering upgrade," says Campbell, "and the second will be more about science." Even at that, Mission 3A, as the October visit is called, has an ambitious agenda (opposite).

Perhaps the most crucial work is replacing the telescope's gyroscopes. There are three of these devices,



A crucial servicing mission for Hubble promises an uninterrupted flow of stunning images from the cosmos.

Telescope Tune-Up

ILLUSTRATION BY DON FOLEY

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A Telescope Servicing Checklist

1 Gyroscopes Three remote sensing units, each containing a gyroscope and a spare, will replace the three currently onboard. Three working gyros are necessary to point the telescope.

2 Voltage Temperature Improvement Kits Six kits, one for each of the six batteries, will make the power conversion and storage from the solar arrays more efficient.

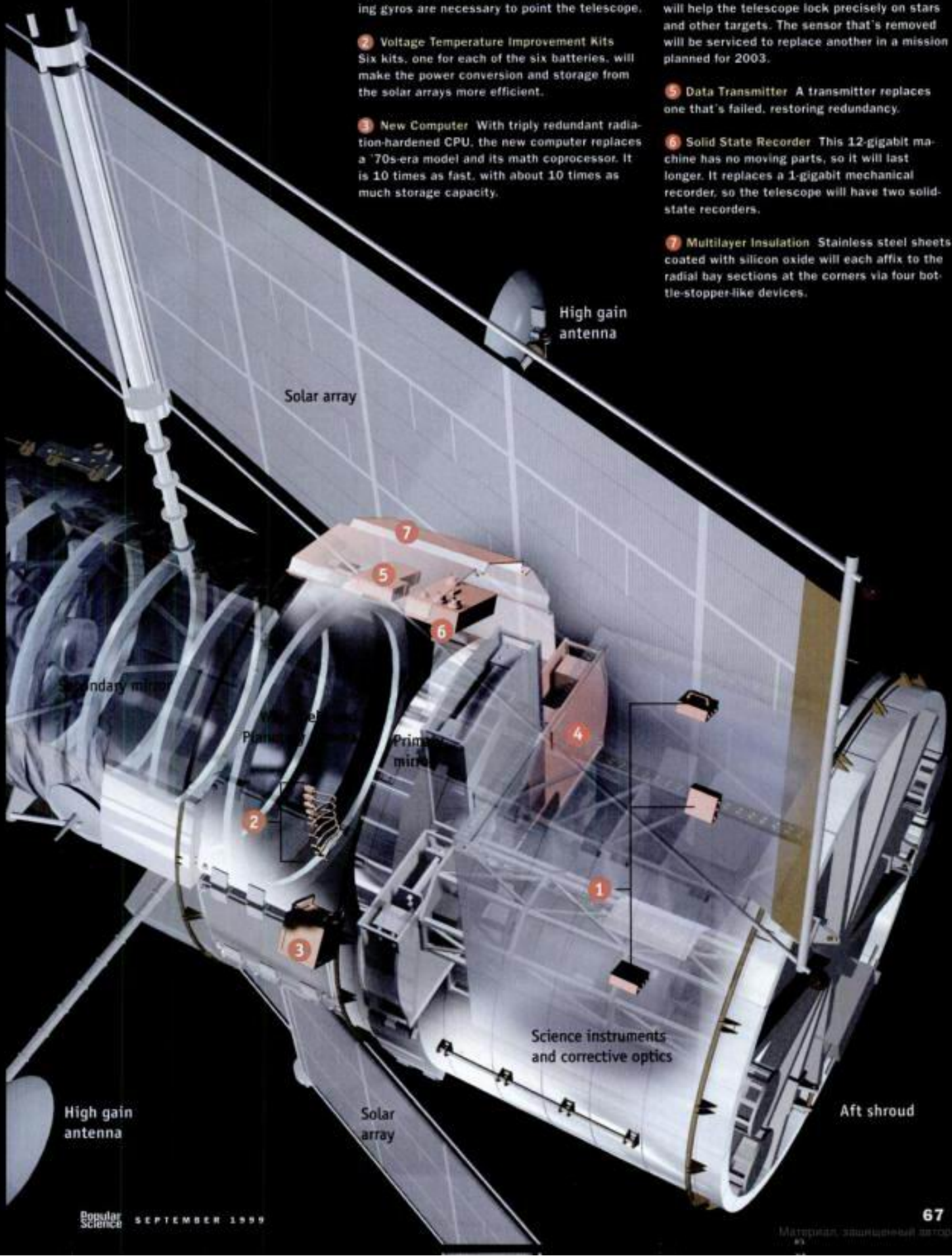
3 New Computer With triply redundant radiation-hardened CPU, the new computer replaces a '70s-era model and its math coprocessor. It is 10 times as fast, with about 10 times as much storage capacity.

4 Fine Guidance Sensor A factor of eight or 10 more accurate than the unit it replaces, a new fine guidance sensor is one of three that will help the telescope lock precisely on stars and other targets. The sensor that's removed will be serviced to replace another in a mission planned for 2003.

5 Data Transmitter A transmitter replaces one that's failed, restoring redundancy.

6 Solid State Recorder This 12-gigabit machine has no moving parts, so it will last longer. It replaces a 1-gigabit mechanical recorder, so the telescope will have two solid-state recorders.

7 Multilayer Insulation Stainless steel sheets coated with silicon oxide will each affix to the radial bay sections at the corners via four bottle-stopper-like devices.



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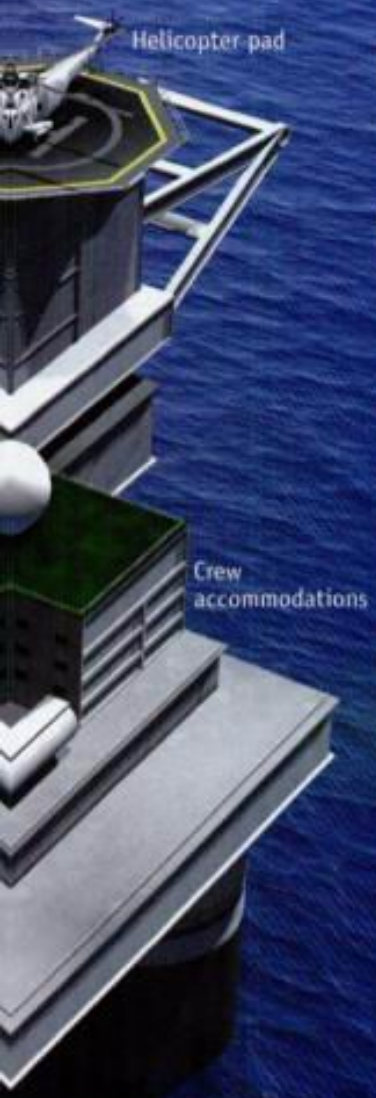
Unlike American rockets, the Russian-built Sea Launch rocket is assembled horizontally—onboard a ship (left). The rocket is mated with its payload, typically a large telecommunications satellite bound for geosynchronous orbit, and then delivered to a second ship that serves as a floating launch pad (right).

From Sea to Space

The shortest route to orbit begins at a satellite launch pad in the middle of the ocean.



By Dawn Stover

STANDING ON PIER 16 in Long Beach, California, I tilt my head back and stare up at a converted oil-drilling platform that towers above me on silo-size columns supported by giant pontoons. Measuring 436 feet long and 219 feet wide, *Odyssey* is one of the world's largest semi-submersible, self-propelled vehicles. It looks more like a skyscraper than a ship.

I take the elevator up to the main deck, about 100 feet above the water, and walk to the ship's stern. It is here that a company called Sea Launch plans to launch its first commercial payload, a television broadcasting satellite that will be carried into space aboard

ILLUSTRATIONS BY MICHAEL SPEIGNER

4-3-2-1, Launch! THE LAUNCH VEHICLE IS assembled onboard the command ship, transferred to the launch platform by crane, stored temporarily in a hangar, and then hoisted into a vertical position for takeoff.

Odyssey launch platform has a rocket hangar and a launch pad.

Sea Launch Commander is both a floating factory and a mission control center.

rocket has a more advanced guidance computer and a stiffer first stage than previous Zenits. "When you've got a 200-foot-tall rocket out in the ocean, the last thing you want is a wobbly rocket," explains Terrance Scott, communications manager for Sea Launch.

The vehicle's payload, a satellite weighing as much as 11,000 pounds, is readied for launch in a processing facility at the home port and then rolled onto the *Sea Launch Commander*. There, in the center section of the ship, the rocket is assembled and mated with the spacecraft. The completed launch vehicle is transferred by crane to the *Odyssey* and stored on its side, unfueled, until both ships arrive at the launch site.

Once at the site, *Odyssey* takes on water ballast to submerge its pontoons about 65 feet underwater for greater stability, a process that takes roughly 8 hours. The rocket is then rolled out and hoisted into a vertical position on the launch pad. Before the rocket is fueled and launched, procedures that are completely automated, *Odyssey* crew members leave their ship by crossing a telescoping bridge to the *Sea Launch Commander*. The command ship then backs off about 3 miles to monitor the launch. "For the last five and a half hours, it's basically all automated," says Donald Carter, Boeing vice president of development and operations for Sea Launch.

The unmanned *Odyssey* holds its position using onboard compasses, a differential GPS system, and a laser targeting system that uses the command ship as a reference point. Electrically powered thrusters on the pontoons make continual adjustments to keep the ship within a few feet of its designated position on the equator. This maneuvering capability is particularly important when the two ships are side by side, with the telescoping bridge between them. The bridge, a first for ships of this size, doesn't leave much room for mistakes.

A Hughes DirecTV satellite will be the first paying customer for the Sea Launch System. Scheduled for a late August or early September launch, the spacecraft may already be in orbit now. If the launch is successful, another will be slated for early next year.

Satellite owners were initially wary of the floating spaceport, in which the Sea Launch partners have invested more than $500 million, but the successful demonstration launch of a mock satellite on March 27 proved that the system works. Sea Launch now has 19 firm orders for launches scheduled over the next three years.

The company is planning six to eight launches per year. Eventually, the two ships could carry as many as three rockets to the launch site simultaneously, although this would require risky at-sea transfers between the ships.

Perhaps the biggest hurdles for Sea Launch are cultural and political, not technological. To facilitate communications between the international partners, the crews of the two ships include 11 interpreters. Even so, there are restrictions on what can be said. Last year, the State Department temporarily suspended work on Sea Launch because of concerns that Boeing may have shared sensitive rocket science with its Russian and Ukrainian partners. Although no classified information was leaked, the company was fined $10 million for alleged improprieties.

www.popsci.com 21st century spaceports

Boeing has a 40 percent stake in Sea Launch, but the rules of the game prohibit the American company from correcting any deficiencies in its foreign partners' technology. "It's like General Motors and Ford getting together to build a car," says Boeing vice president Carter. "We don't solve their technology problems for them."

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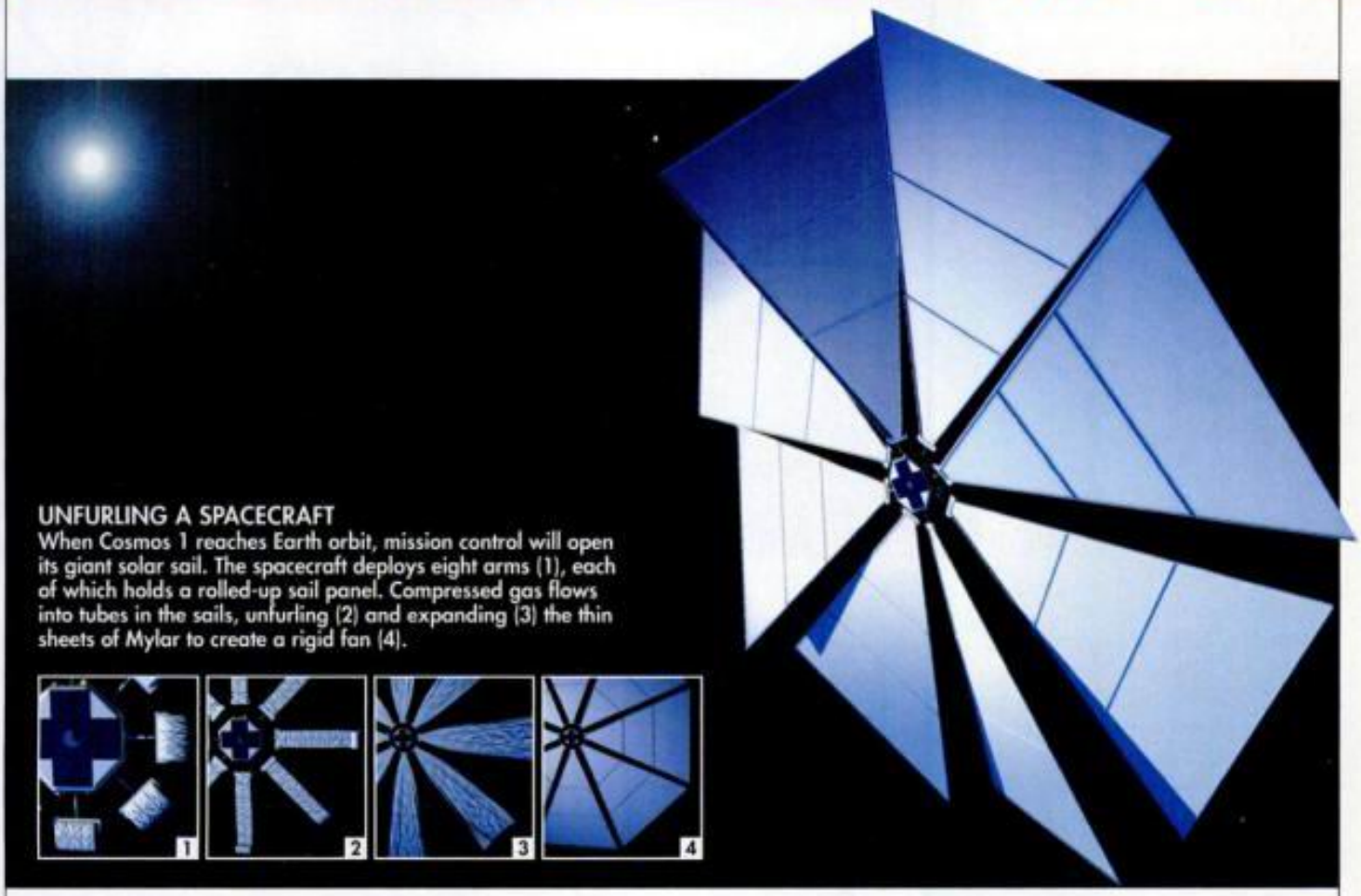
News Files

EDITED BY CHARLES HIRSHBERG with GUNJAN SINHA



UNFURLING A SPACECRAFT
When Cosmos 1 reaches Earth orbit, mission control will open its giant solar sail. The spacecraft deploys eight arms (1), each of which holds a rolled-up sail panel. Compressed gas flows into tubes in the sails, unfurling (2) and expanding (3) the thin sheets of Mylar to create a rigid fan (4).

space travel

Space Sailing by Sunlight

And you thought windsurfing was a rush.

EVER SINCE SPACE TRAVEL BEGAN, THERE HAS BEEN exactly one way to reach the heavens: rocket engines. But now an entirely new approach is set to launch—a strategy that fights the unyielding pull of gravity with the gentle push of sunlight. The anticipated December blastoff of the Cosmos 1 spacecraft from a Russian submarine will debut the age of solar sailing.

Solar sail spacecraft may one day surpass rocket-propelled flight, especially for long journeys, by drawing on a nearly limitless propellant: sunlight. Light is made up of tiny packets of energy called photons, which may be thought of as both waves and particles. Solar sails reflect these photons and push them back. Since each action has an equal opposite reaction, each time a photon is reflected, it in turn pushes back on the spacecraft, slowly accelerating it out into the galaxy.

The Cosmos 1 mission is funded by The Planetary Society, a space exploration advocacy group, and Cosmos Studios, a media company headed by Ann Druyan, widow of astronomer Carl Sagan. The mission's goal is to demonstrate that sunlight can affect a spacecraft's trajectory. Success will be measured not in miles traveled, but by how much the sun alters the spacecraft's course.

Another mission, one that uses a solar sail to get somewhere, may not be far behind. A company called Team Encounter, of Houston, Texas, is building what it calls Humanity's First Star-

(CONTINUED) ►

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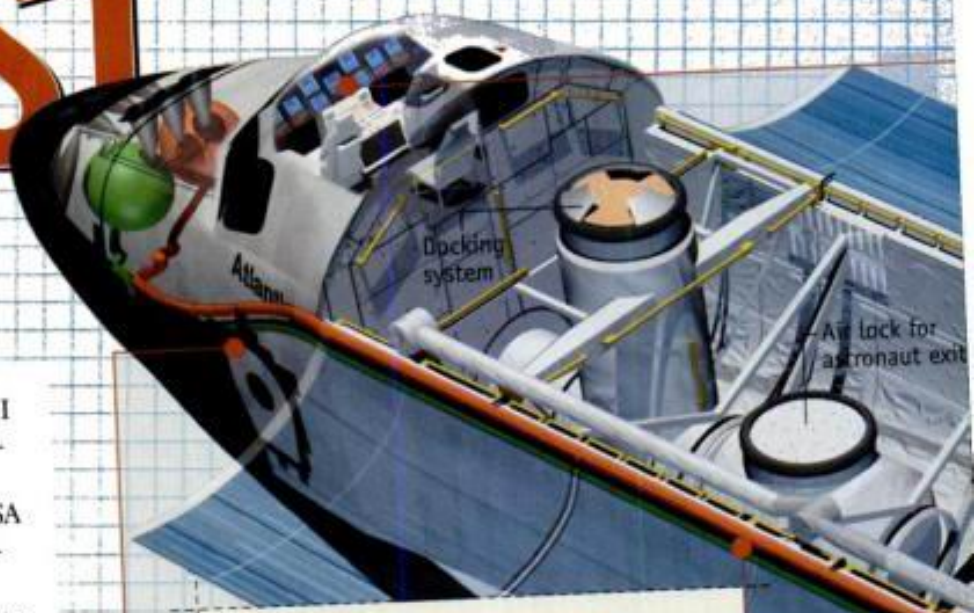
Shuttle Gets a Boost

Thanks to a series of upgrades, the space shuttle will be flying high for years to come.



By Philip Chien

CRAWLING ON MY hands and knees, I enter one of the most distinctive vehicles on or off this planet—the space shuttle Atlantis. I'm here because NASA has agreed to let a handful of journalists get an unprecedented firsthand look at Atlantis' new "glass cockpit," an array of colorful digital displays that has replaced the shuttle's original panel of difficult-to-read gauges and monochrome cathode-ray screens.

The glass cockpit was recently installed as one of more than a hundred major modifications to Atlantis. Soon NASA's other three shuttles will also receive cockpit makeovers.

The space shuttle was designed in the 1970s, first flown in 1981, and may continue to operate for another 20 or 30 years if a viable successor isn't built. A demonstrator for a shuttle replacement is to appear next summer; the full-scale craft would be built several years after that. But as with the B-52 bomber, it's quite possible that the

New Plumbing for Thrusters

THE AFT THRUSTERS have larger propellant tanks than the forward thrusters. So forward propellant is always a limiting factor for rendezvous. Additional plumbing will permit the aft tanks to share propellant with the forward thrusters, a capability considered necessary for maintaining the space station's orbit.

Avionics Improvements

IT'S HARD TO FIND spare parts for 1970s-era avionics, so outdated components are being replaced with off-the-shelf units that are cheaper and easier to maintain. For example, a solid-state data recorder will do the work of three old computers while using only one-fourth as much power. The recorder should be flying by 2002.

ILLUSTRATIONS BY BOB SAULS/ JOHN FRASSANITO & ASSOCIATES

Glass Cockpit

LIQUID-CRYSTAL DISPLAYS replace 1970s-vintage screens and gauges. The displays show graphic versions of flight instruments in color, bringing important items to the astronauts' attention immediately and giving more information about what's happening during critical situations.

Main Engine Improvements

ALREADY FLYING are engines with more reliable pumps, improved injectors, and lower-pressure nozzles. Under consideration are new sensors to monitor engine performance, including vibration detectors and a pollution sensor, similar to the one in your car, that will detect any foreign materials leaving through the exhaust.

New Cooling System

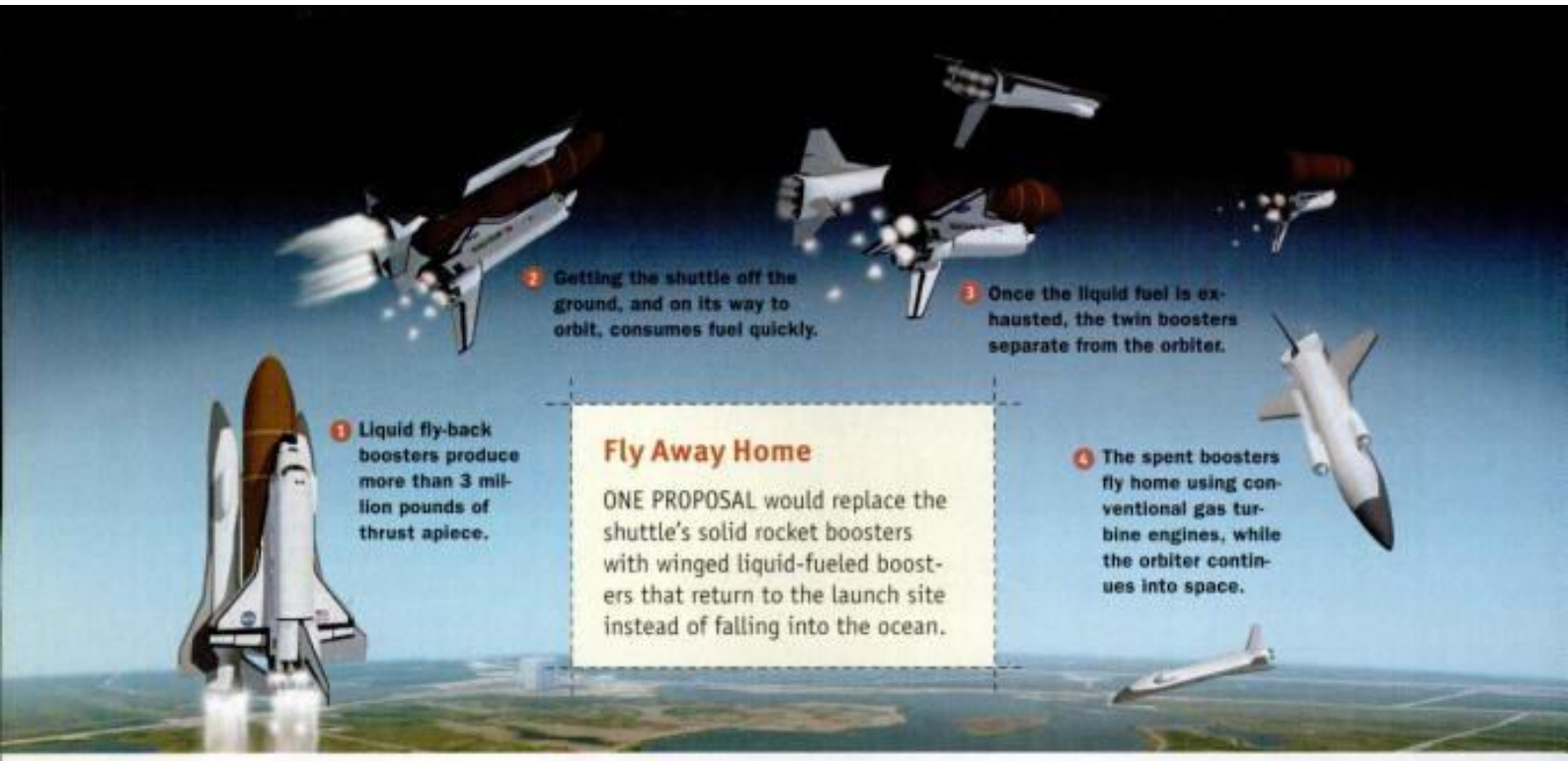
UNDER CONSIDERATION is a device that would evaporate water from a porous Teflon surface. The evaporating water would remove heat, just as evaporating sweat makes you cooler on a hot day. The proposed system would be easier to maintain than the current Freon loops, which are similar to a refrigerator.

Cargo bay

Liquid fuel tanks

Debris Protection

NASA DID A STUDY to determine where a piece of orbital junk or a micrometeoroid would do the most damage if it did hit the shuttle. The areas of concern proved to be the leading edge of the wings and the radiator loops on the inside of the cargo bay doors. Extra insulation has been added to the wings, and the radiator lines have been wrapped with aluminum tape.



Fly Away Home

ONE PROPOSAL would replace the shuttle's solid rocket boosters with winged liquid-fueled boosters that return to the launch site instead of falling into the ocean.

shuttle may survive long enough for the sons or daughters of today's pilots to fly it in the future.

Over the past 18 years, NASA has made a series of improvements to increase the shuttle's safety, reliability, and performance—spending about $100 million a year on modifications and upgrades. Most of these changes have been "under the skin," seen only by those responsible for their installation and maintenance.

But now, NASA is in the same situation as any car owner—do you keep driving your current vehicle and make repairs as required, or do you buy a new car? For now, the agency has decided the shuttle is worth keeping.

While it has certainly had its share of budget overruns and technical troubles, the space shuttle has turned out to be the most versatile spaceship ever designed. It can serve as a platform for research instruments, a truck to carry cargo to and from space, a temporary laboratory in orbit, and a work platform for astronauts to assemble or repair other spacecraft.

Even as scientists are planning new jobs for the shuttle to do, engineers are working on improvements to keep it flying. Among the major changes that have already been made are safety enhancements to the main engines. NASA's safety analysis shows an 82 percent reduction in the chance of a catastrophic failure (the loss of the vehicle and crew) from 1992 to 1999. The odds of losing a shuttle on any given flight are now estimated at one in 438.

But safety improvements are just a few of the recent upgrades developed for the shuttle. Others include:

• A super-lightweight external tank. With a lighter fuel tank, the shuttle can now carry up to an additional 7,500 pounds of payload into orbit.

• Off-the-shelf notebook computers and camcorders. They're more versatile and powerful than the super-expensive equipment originally designed for the shuttle, and can be used for many noncritical applications.

• Non-Freon insulation. The orange foam that insulates the shuttle's external tank was originally sprayed on with Freon. More environmentally

Lightening Columbia's Load

ENGINEERS USED extremely conservative information to design Columbia, the oldest space shuttle. Later shuttles benefited from Columbia's early flight experience, and NASA was able to save weight in their design, which translates into greater payload-lifting capability.

The newer shuttles use a 3,500-pound Orbiter Docking System (ODS) to visit space stations. With that extra weight, Columbia can't lift enough cargo to make the trip worthwhile. But if the heavy ODS could be eliminated, Columbia could help with station work, adding flexibility to the shuttle schedule.

The commercial company Spacehab has come up with a method for getting rid of the ODS. Spacehab is using its own funds to develop a system called the Double Docking Module. This is a modification of the company's existing cargo module that adds a docking ring on top. As an additional bonus, the module moves the center of gravity aft—increasing the amount of useful payload, permitting payloads to be loaded later than with other cargo carriers, and allowing bulky payloads to be carried straight into a space station without having to maneuver the 90-degree turn through the ODS.

Spacehab cargo modules have been used for seven flights to the Mir space station and are planned for at least two International Space Station resupply missions. Spacehab hopes to have its Double Docking Module ready by 2001.—*P.C.*

RENDERINGS BY TRACY BOYLE

Court house

Four 24-foot-square modules and smaller four-foot-square modules with few interior bearing walls form the basis of this playful courtyard house. The arresting roof, though complex looking, is easy to build, according to designer Charles Woods. "The soaring planes are just four gable roofs with large skylights for passive solar heating and six-foot diamond-shaped windows in the gable ends," he says.

Woods intended this plan, which employs a number of new materials and technologies, to display an eclectic mixture of influences: geodesic domes, Arabic and Roman courtyards, even modular space stations. The design, though loyal to the modern tradition, is reminiscent of organic architect Bruce Goff's early work.

The house is large, at 3,750 square feet. Though the design results in a lot of wall surface exposed to the weather, the house should remain comfortable and efficient with proper insulation: R-45 in the roof and R-25 in the walls might be typical for moderately cold climates. The north and west sides are sheltered with five-foot earth berms. Woods's design incorporates active/passive solar heating and specifies radiant floor heat: Butyl rubber tubing is laid in the insulated concrete slab, and hot water from the solar collectors circulates through the tubes to heat the floor. Where heating and cooling demands justified, an earth-coupled heat pump could be installed.

The earth berms help improve comfort in both winter and summer because soil minimizes temperature swings, both diurnally *and* seasonally. Also, the large overhangs and use of low-transmittance heat-reflective glass in all but the south-facing windows help prevent summer overheating. The south-facing skylights are intended to have double panes of low-emissivity glass. Some could be opened and closed by remote control. Motorized shades could be fitted to control summertime light and heat.

The berms necessitate careful attention to waterproofing. Woods recommends insulating the outside of the walls with rigid foam insulation and sealing them with acrylic waterproofing and butyl rubber sheeting. Besides the conventional concrete foundation, Woods provides details for an optional pressure-treated wood foundation using 2×10s, fiberglass insulation, plywood, and rigid foam sheathing.

From the foundation we go to the rooftop: Woods specifies newly developed fiber-cement shingles, which bear a striking resemblance to slate. And they last like slate as well, up to 50 years. Another unusual roof treatment: planters lined with butyl rubber and equipped with copper drains, then filled with 12 to 16 inches of soil and low-maintenance plants. A third feature of the extraordinary roof is the glazing surrounding the chimney. Woods provides two construction details, depending on the climate of the house location.

That clerestory skylight hovers 22 feet above the vaulted great room. The great room opens onto a 32-foot octagonal courtyard with planters and a reflecting pool. Patios frame the room on two sides. Through a gallery passageway is the dining and kitchen module, where an enclosed eight-foot spiral stair ascends to a family room with 13-foot sloped ceilings. From there you have a view down to the dining and kitchen areas and across to other modules. The bedroom module is next, through another gallery. Two bedrooms and a bath occupy the first floor. Upstairs is the master bedroom suite, which includes a large bath and two closets. The last module houses a two-car garage and mud room, with a storage loft above.

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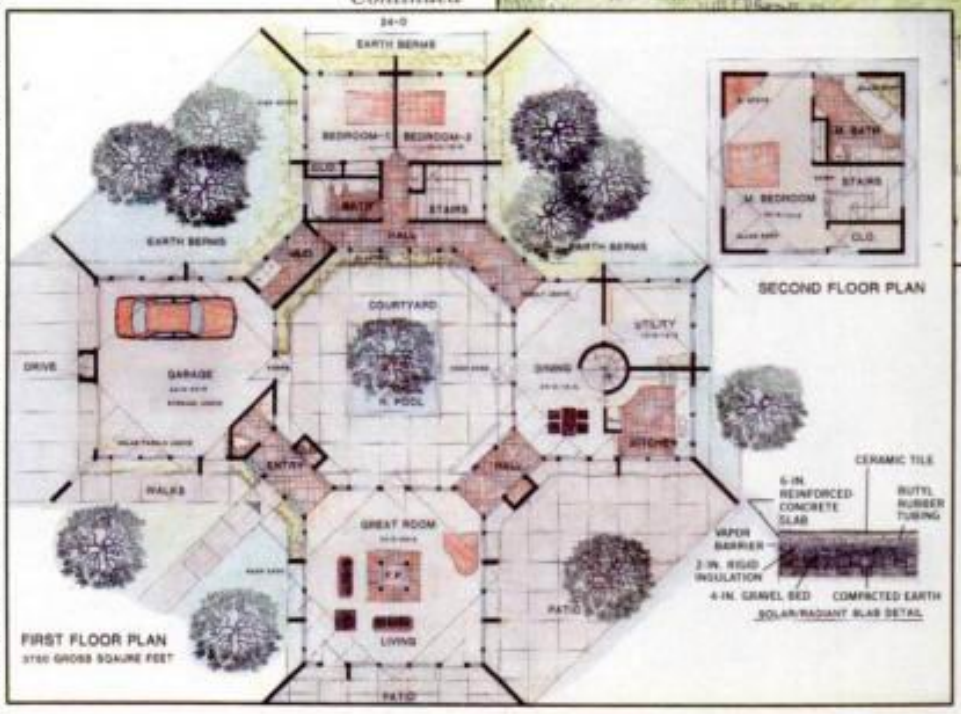

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Fire in the Sky

National Missile Defense

THE U.S. PLANS to deploy high-flying interceptors that would destroy enemy ballistic missiles carrying nuclear, chemical, or biological warheads.

Set for launch in 2004, the spaced-based infrared sensor (SBIRS) is designed to be a supersensitive eye in the sky that would monitor potential missile launch sites.

One or more interceptors would launch to attack the enemy warhead. As it drew near the target, an autonomous kill vehicle would separate from the booster. The kill vehicle would then maneuver to collide with the enemy warhead and destroy it.

Radar would continue to track the enemy missile as it sped toward the United States. High-resolution radar would provide a detailed look at the incoming enemy warhead.

The momentum behind a national missile defense system seems unstoppable. But do we need it, and will it work?

By Frank Vizard

A MINUTEMAN II ROCKET specially configured to simulate an enemy ballistic missile will launch from Vanderbilt Air Force Base in California on August 12 and head west across the Pacific Ocean. Some minutes later, as the projectile rises high over the sea, another missile will launch from a military base on a small and very isolated atoll called Kwajalein in the Marshall Islands.

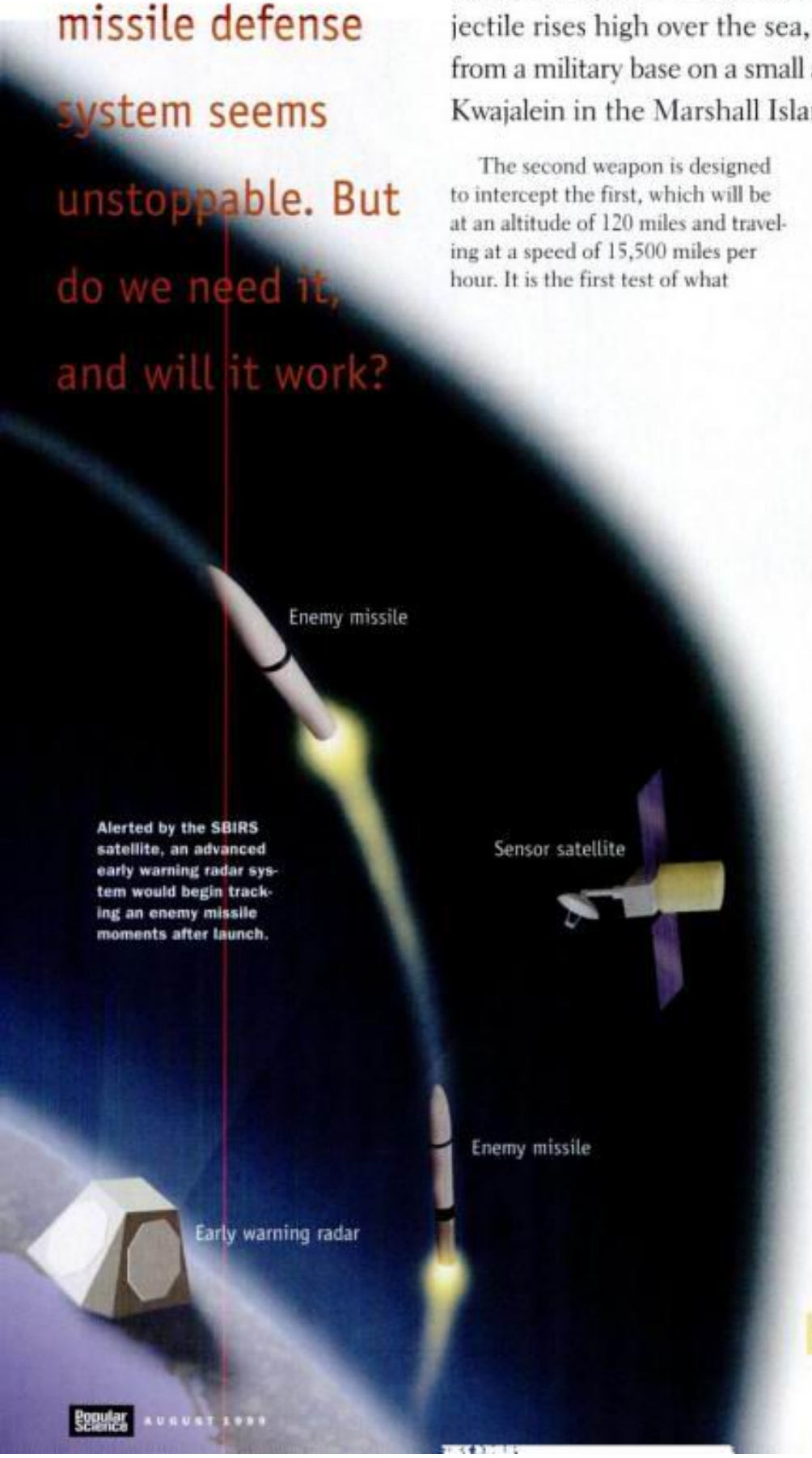
The second weapon is designed to intercept the first, which will be at an altitude of 120 miles and traveling at a speed of 15,500 miles per hour. It is the first test of what promises to be a national missile defense system whose purpose is to thwart incoming long-range enemy missiles targeting the United States, including Alaska and Hawaii, and carrying warheads containing nuclear, chemical, or biological weapons.

This testing may come as a surprise to many who have assumed that the United States already possesses a defense against intercontinental ballistic missiles. What the United States possesses is a deterrent, not a defense. This deterrent is based on this country's offensive missile capability; any attack on us would foster an overwhelming nuclear strike in reply.

And while some critics say that this deterrent is enough, the government is increasingly seeing the need for a shield that would serve as an alternative to reducing some spot on the planet to a nuclear wasteland. Such a move has major political consequences both domestically and overseas.

Over the next several months, the Clinton administration and Congress will begin wrestling with the thorny issue raised by the test in the Pacific. As currently envisioned, deployment of the government's national missile defense plan violates the 1972 Anti-Ballistic Missile Treaty negotiated with the former Soviet Union.

Implementing a national missile defense system means the treaty will have to be renegotiated or the United States will have to withdraw. Such a



Alerted by the SBIRS satellite, an advanced early warning radar system would begin tracking an enemy missile moments after launch.

ILLUSTRATIONS BY BRIAN CRAGIN

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Hitting a Bullet with a Bullet

THE NATIONAL MISSILE defense system relies on the notion that one missile can intercept and destroy another. While this concept has worked against smaller rockets, its validity against fast, long-range missiles is unproven. Destroying an enemy missile is the mission of the autonomous kill vehicle.

decision, though, may have adverse effects on nuclear and even nonnuclear missile proliferation if Russia or another country decides it needs to counter a U.S. defensive system by increasing its offensive stockpiles. Since Congress overwhelmingly passed legislation this spring supporting a national missile defense initiative, however, the ABM treaty stands in the way of a political juggernaut that appears unstoppable.

The decision to begin construction of a national missile defense system won't be made until next June or July. By then, only four of the 13 tests scheduled for the next few years will be completed, which means that a decision may be made without all the technical results in hand. Because 2000 is a presidential election year, most political insiders believe the decision will indeed be made before all the test scores are in, and that a national missile defense system will be in place by 2005.

So how credible is the threat, and is it worth spending $10.5 billion over the next six years to build a defensive shield? Russia, with an estimated 7,000 nuclear missiles capable of hitting the United States, is still the biggest threat from a numerical standpoint. Supporters of a national missile defense, however, play down the threat from Russia and other members of the former Soviet Union like Ukraine and Kazakhstan, citing reduced tensions brought about by the end of the cold war.

In any event, the planned system isn't designed to forestall a massive missile attack that Russia could mount. Building a Reagan-esque Star Wars-type system to defend against the thousands of missiles Russian possesses would cost too much money. Rather, the planned system is designed to defend against an accidental launch or an attack of a small number of missiles by a "rogue" nation.

The threat of accidental launch has been around for decades, of course, but hasn't prompted this level of rhetorical concern before. What is new in the weapons of mass destruction mix is the widespread proliferation of ballistic missiles in recent months among countries like India, Pakistan, North Korea, Iraq, Iran, China, and Libya, as Defense Department intelligence officer Dr. David J. Osias, a specialist in arms control issues, points out. With the exception of North Korea and China, Osias believes none of these countries possesses missiles with the range to hit the United States.

One year ago, North Korea launched a No Dong missile with a third stage in what the intelligence community now believes—and as was claimed at the time—was a failed attempt to launch a satellite into orbit. Initially, however, surprised U.S. officials believed it to be a test of an intercontinental missile. The No Dong 3 could reach our shores, but Osias

Craft powered by antimatter, fusion, and solar-driven

Ramjet Fusion Engine

IN ONE interstellar-engine concept, charged particles streaming out at one-third the speed of light would provide thrust for a fusion-powered spacecraft.

Distance to a Star

THE NEAREST STAR is a long way from Earth: Distances are in astronomical units, or AU. One AU is the distance between Earth and the sun, about 93 million miles. The map is not to scale.

sails could take us to interstellar space.

Star Travelers

By Mariette DiChristina

ROBERT FRISBEE IS HUFFING cheerily as he ambles downhill toward a nondescript building on NASA's Jet Propulsion Laboratory campus in Pasadena, California. The San Gabriel mountains form a stunning backdrop, and the sun has warmed the January air to spring-like temperatures, but Frisbee doesn't seem to notice any of it. Indeed, his mind is far away. In interstellar space, to be exact. Frisbee is talking about how we'll someday visit the stars with spacecraft.

If that sounds far out, it is, by nearly every measure you can think of—the tremendous distances between stars, mission trip times measured in decades, and required technological advances so dramatic that even some researchers refer to them as "miracles." Nevertheless, there's no shortage of well-reasoned ideas about how to conquer the

ILLUSTRATIONS BY BOB SAULS/ JOHN FRASSANITO & ASSOCIATES

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"final frontier." Frisbee and others at NASA centers, universities, research institutions, and companies are laying the groundwork for experiments that will advance the necessary technologies. And while depicting trips to other stars has long been a staple for science fiction writers, today it is the stuff of long-range strategic goals for NASA. The NASA Origins program plans a series of progressively more capable telescopes, culminating in the imaging of Earth-like planets around the nearest 1,000 stars. Building on that, NASA Administrator Dan Goldin has said he wants the agency to launch interstellar missions in the next 25 years. To drive the necessary advances, "We have to set goals so tough they hurt," Goldin has said.

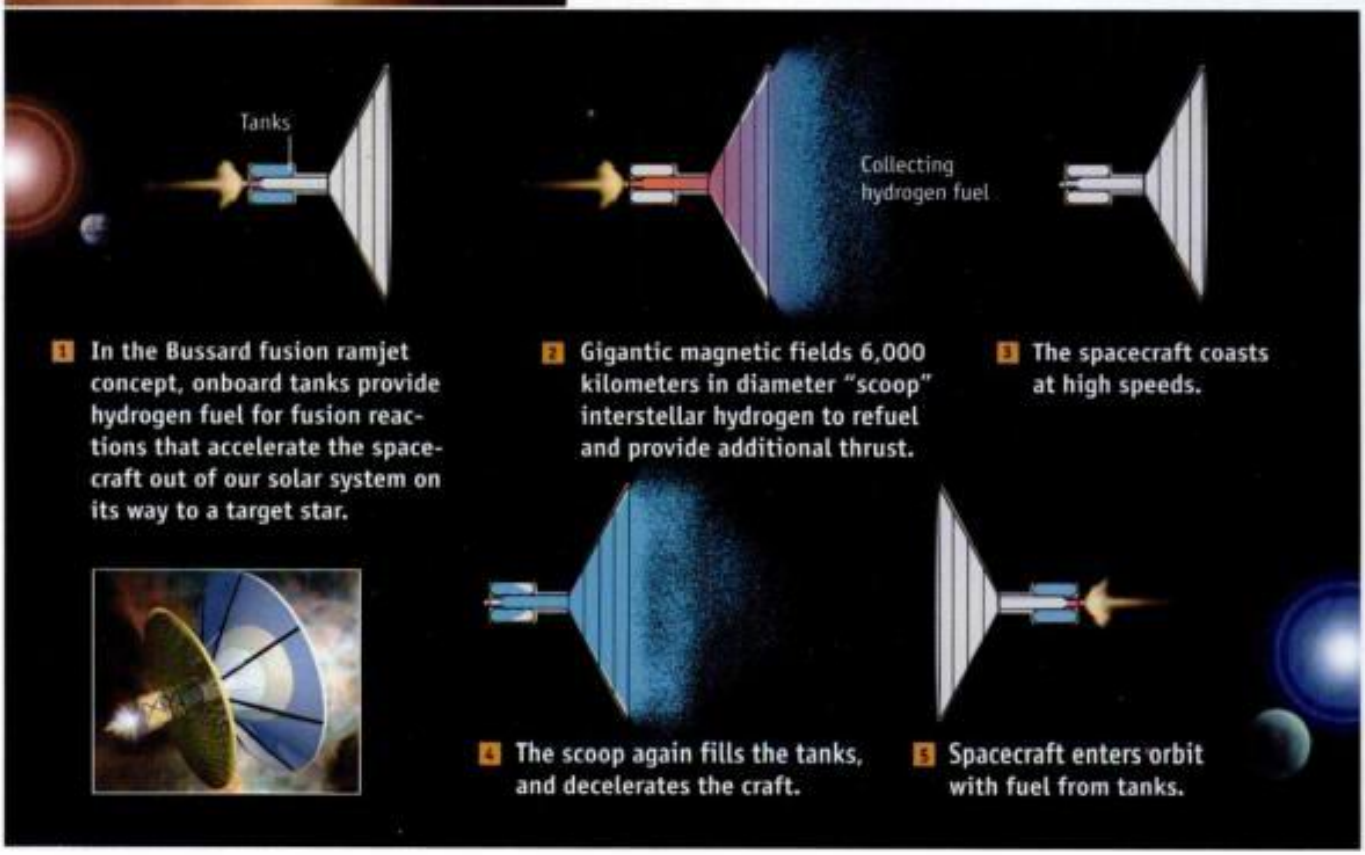
Even at this embryonic stage, it's already more than apparent that the task is as difficult as it could possibly be and still remain possible—scientists *think*. Start with the vast scale of the cosmos. Voyager I, launched September 5, 1977, illustrates the scope of the problem. After speeding along for more than 20 years, it is now 6.8 billion miles away from Earth traveling at nearly 51,000 mph. That's about 10 light-hours away. (A light-hour is the distance light travels in one hour at 186,000 miles per second.) But the closest star to Earth is Proxima Centauri, which is 4.3 light-*years*, or 25 trillion miles, away. If Voyager were pointed in the right direction, Frisbee and JPL colleague Stephanie Leifer calculate that it would take some 74,000 years to make the trip. But interstellar missions must occur on a human time scale—preferably within an individual's lifetime. That means a maximum of 40 years for a "slow" mission, and a far more desirable 10 years for a fast one.

And then there's Einstein. A spacecraft that aims to cross vast distances at high speeds also must contend with the theory of special relativity. The theory mandates that as an object approaches the speed of light, its mass increases. To get to Proxima Centauri in, say 10 years, the craft would have to whiz along at nearly half light speed. At that velocity, it would become 1½ times more massive than it was originally. Frisbee, a chemist whose job it is to analyze such missions, puts it another way: "If you take a 1-ton spacecraft, such as Voyager, and bring it up to one-half the speed of light, it'll require one month's worth of all the energy produced today by humans." Even if it were possible to build a big enough fuel tank, conventional chemical rockets don't have the power, or energy density, to do the job.

One last thing: It's one kind of propulsion requirement to get up to speed and coast for a fly-by mission, as Voyager did to the outer planets in our solar system. But to stop to orbit or land at an interstellar target, the spacecraft has to expend energy to slow down. "From a propulsion point of view," says Frisbee, "we've immediately doubled the requirements."

So what's an interstellar mission planner to do? "When all is said and done, you're kind of stuck with fusion or antimatter [for an onboard engine]," says Frisbee. "Even fission doesn't have enough energy." The other chief option, he says, is to leave the engine at home. Solar-powered lasers parked in orbit around our sun, for instance, could push craft with

FUSION RAMJET



1 In the Bussard fusion ramjet concept, onboard tanks provide hydrogen fuel for fusion reactions that accelerate the spacecraft out of our solar system on its way to a target star.

2 Gigantic magnetic fields 6,000 kilometers in diameter "scoop" interstellar hydrogen to refuel and provide additional thrust.

3 The spacecraft coasts at high speeds.

4 The scoop again fills the tanks, and decelerates the craft.

5 Spacecraft enters orbit with fuel from tanks.

thin sails across space. "Right now, based on our current level of ignorance, they're all equally impossible . . . or possible," says Frisbee.

Take antimatter, for instance. If antimatter comes in contact with regular matter, they annihilate; the mass of both is turned into energy. "The antimatter-matter reaction has the highest energy density we know of," says Stephanie Leifer of JPL. The reaction releases charged particles, which could be directed out the back of a spacecraft for thrust using magnetic "nozzles." The charged particles move very fast, approximately one-third the speed of light. However, says Leifer, "We don't know how to make nozzles big enough [for an antimatter engine]. It's not totally infeasible, but it's very tough."

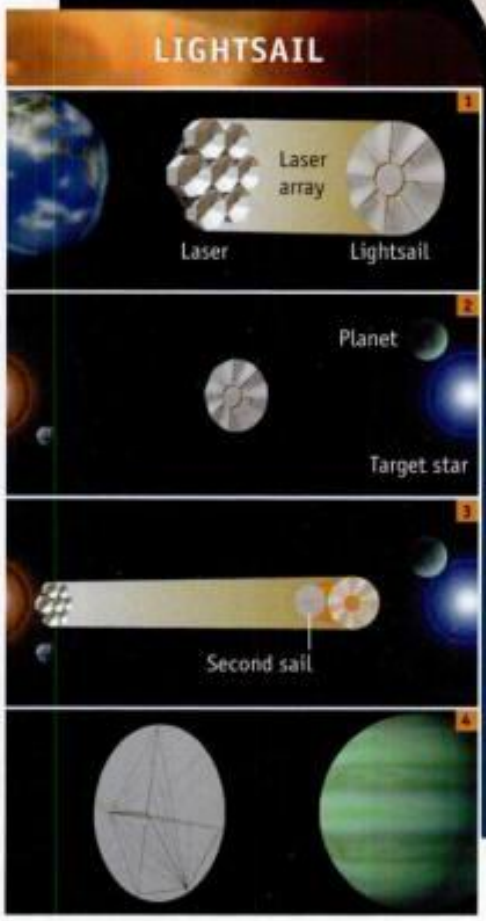
Add to that another big problem. A pure antimatter engine would need thousands of tons of antimatter, plus matter, on the order of the size of the Washington Monument. But today, mere nanograms of antimatter are made at special laboratories like Fermilab and CERN. "We'd probably have to have an infrastructure in space, to harvest the antimatter," speculates Leifer.

The effort might be defensible, since antimatter could be used for medical applications like imaging and destroying certain cancer tumors. But then there's another issue. Antimatter also can't contact matter, so it's been difficult to store more than a tiny amount in magnetic traps, which keep charged particles from hitting the matter containment walls and annihilating.

Enter physicist Gerald Smith and his team at Penn State. Smith suggests a way to vastly reduce the antimatter requirements. "We'll never have even a ton of antimatter, in my view," he says. "We think we can ignite with a microgram of antimatter, which we can foresee doing with the current technology." Ignite what? A fusion reaction.

His team is attacking the problem on several fronts. First, successful tests with a shoebox-size antimatter trap built at Penn State that could theoretically hold 100 million antiprotons, or positively charged particles of antimatter, have inspired researchers to build a larger one with the Marshall Space Flight Center in Huntsville, Alabama, to be finished this summer. Smith estimates it could hold 10,000 times as many antiprotons as the smaller trap. The trap will enable eventual tests with a planned antimatter plasma gun, which will be used to ignite the fusion reaction.

Nuclear fusion, which happens in



SOME TENS OF KILOMETERS in diameter and just a few atoms thick, lightweight lightsails, 1., would be pushed by an orbiting laser beam powered by the sun for a 4.5 light-year trip to another star in 20 years.

2. After being pushed for months or years, the sail spacecraft would coast to the target star system.

3. A second-stage sail would be used to decelerate; 4. then the lightsail goes into orbit around a selected planet.

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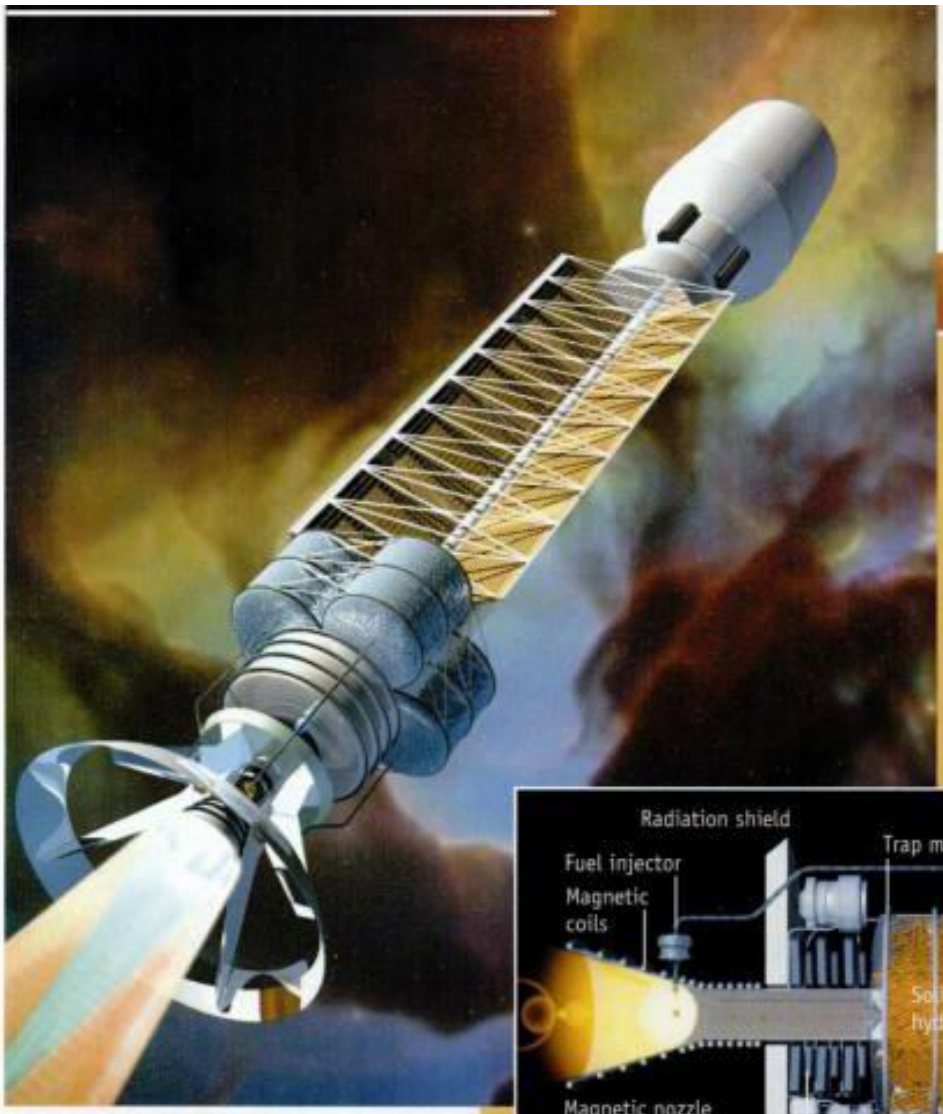
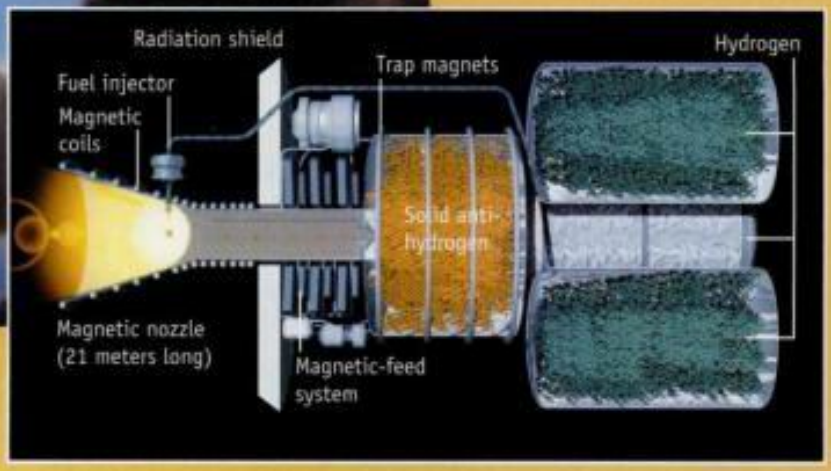


MATTER-ANTIMATTER

WHEN MATTER CONTACTS antimatter, they annihilate each other, releasing energy in greater densities than any other reaction known. In a beam-core engine system concept, hydrogen and anti-hydrogen are fed from a spacecraft's onboard storage tanks. They contact in a chamber and the resulting products are directed out the back of the spacecraft by magnetic "nozzles" for thrust.



the hearts of stars like our sun, requires tremendous pressures and temperatures. "Low" temperature fusion starts at 1.5 million degrees Celsius. The antimatter plasma gun is intended to create temperatures hot enough to trigger fusion. To date, experiments with fusion have managed to maintain the reaction for only a few seconds before it burns out.

That's where the third part of Penn State's efforts, developing engine concepts, comes in. Smith's Aimstar engine concept offers a way to maintain the fusion reaction. It starts with a small amount of antimatter, which comes into contact with lead or uranium, causing it to fission. The energies released by the fission help drive the fusion reaction of deuterium, or "heavy" hydrogen, and a form of helium. The high temperatures create a plasma of negatively charged electrons and the positive nuclei of atoms. Magnetic nozzles direct the charged particles for propulsion.

Missions in search of other planets www.popsci.com

But with such hot temperatures, wouldn't the nozzles be destroyed? "I'm working on that," promises Smith.

Another Smith concept gets around the problem of melting by, in effect, melting away only a little at a time. "We're working our heads off to move forward as fast as we can," he says. "Because if there's a technology that's capable of going to the stars, it's antimatter."

Another fusion approach, called the Bussard Ramjet, attempts to solve the weight problem by not taking much fuel at all. Instead, the concept calls for a gigantic magnetic field "scoop" that would harvest what it needs from interstellar space. The scoop is, of course, far bigger than any that has ever been generated on Earth—about the distance from Earth one-third the way to the moon, at a strength hundreds of times what is possible in labs today. Leifer of JPL describes the system: "You need to pick up your fuel, compress it and heat it, and expel it out the back without slowing down the spacecraft," she says, "and we don't know how to do that either."

Solar sails may be initially more promising than antimatter or fusion, says Frisbee. "In terms of a closest and cleanest development program, solar sails may be the first step." The idea was first conceived decades ago by Robert Forward, a retired Hughes physicist who now consults for NASA; heads Forward Unlimited, a Clinton, Washington, company that

Curved Crossing

A 770-ton steel and concrete bridge winks open like an eye to let passing ships through.

ILLUSTRATIONS BY DARREN BLUM

By Mariette DiChristina

AS THE TALL SHIP approaches, the bridge controller opens the low-slung structure on the Tyne River in northeast England. The bridge's two arches—one a curved horizontal path for cyclists and pedestrians, and the other arcing vertically overhead for support—tilt 40 degrees from their original positions on two pivot points located on each side of the river. Like an opening eyelid, the whole structure slides up. Fully open, the two arches, connected by cables, curve over the ship like an awning. A 770-ton steel and concrete awning, that is.

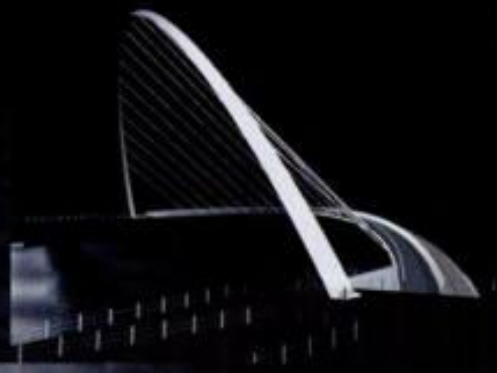
"It will be a spectacle," promises Keith Brownlie, project architect of the Baltic Millennium Bridge, which is to be completed by the end of 2000. The $24 million bridge, which was to have begun construction in April, will link new housing and cultural projects in Gateshead and Newcastle. A panel of judges chose the design in a competition that drew more than 150 entrants from around the world.

The unique design echoes the nearby seven-decade-old Tyne Bridge's distinctive arch, says Brownlie, of Chris Wilkinson Architects in London, which created the Baltic with civil engineers Gifford and Partners of Southampton. "We wanted to tip our hats to the Tyne Bridge in a new form," adds Brownlie.

The Baltic will have a conventional steel superstructure, protected by new, more durable glass-flake epoxy paints. Pedestrians will use an inner solid steel walkway, and bicyclists the outer 1-foot-lower deck made of aluminum with gaps for viewing the river. Lamps built into the decks will light the paths at night. While the river is about 410 feet wide measured between banks, bridge crossers will travel 446 feet around the bridge's curved path.

In addition to serving the 3 million or so people that are expected to be drawn to the new construction on both sides of the Tyne, the bridge that opens like an eye is likely to become an attraction in itself. With pun intended, "It'll be a wonderful sight," says Steve Richards, director of engineering services for the Gateshead Metropolitan Borough Council.

When it's raised completely (left), the Baltic Millennium Bridge will form a grand archway over the Tyne River in northeast England for boats to pass underneath. The bridge will slide closed like an eyelid (right), providing a curved crossing for pedestrians and cyclists. The Baltic Bridge's construction is scheduled to be completed by the end of next year.



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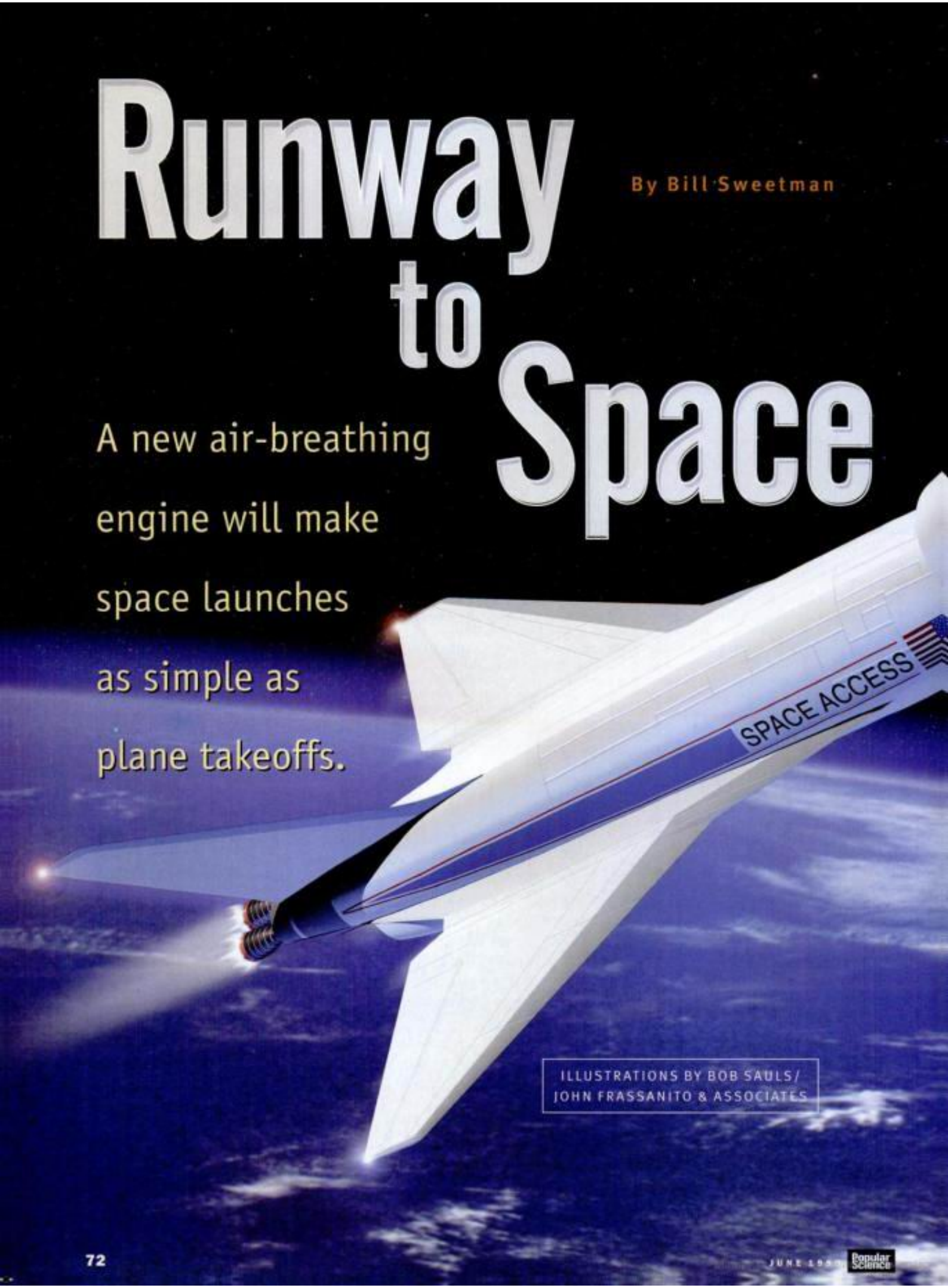
Runway to Space

By Bill Sweetman

A new air-breathing engine will make space launches as simple as plane takeoffs.



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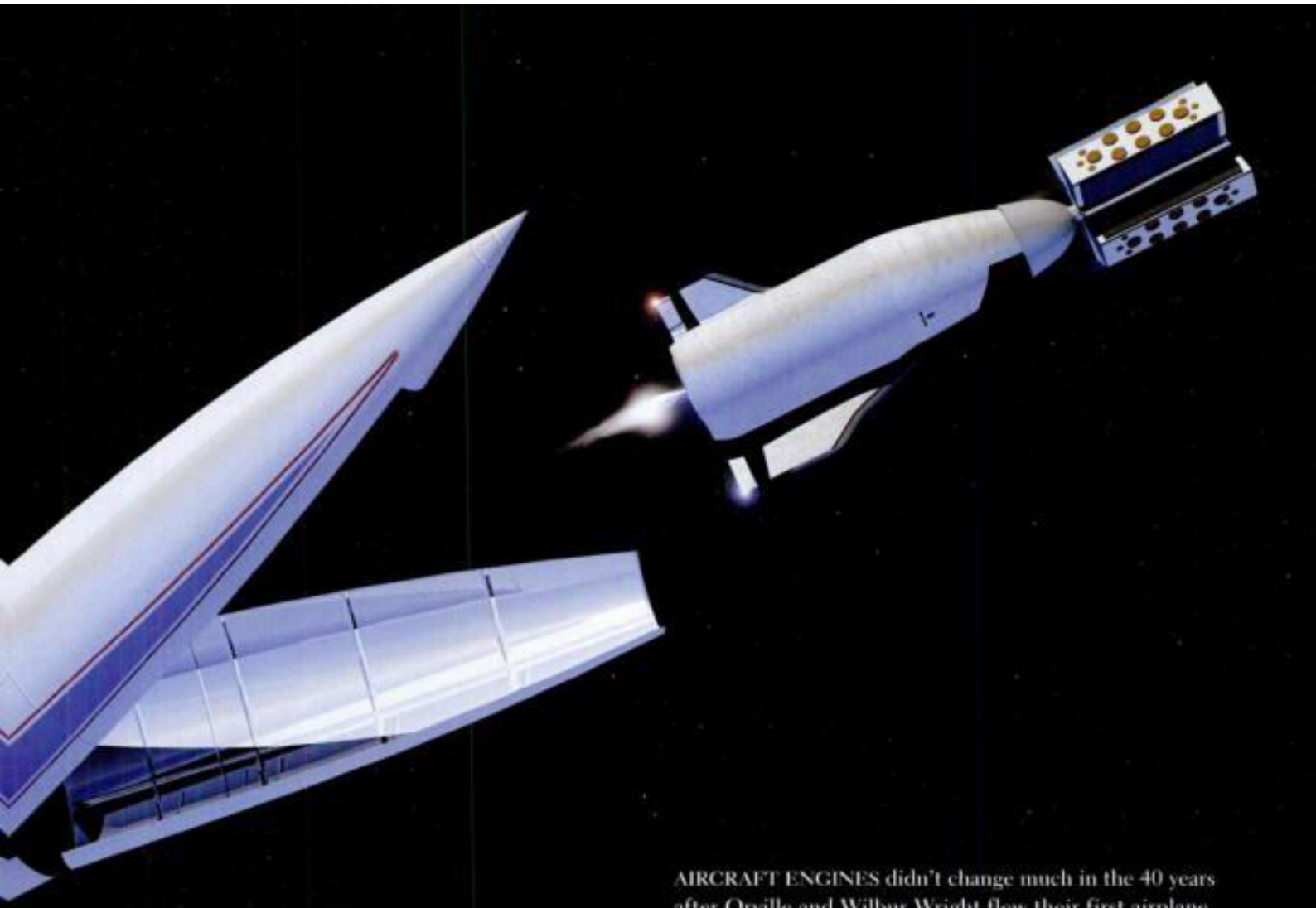
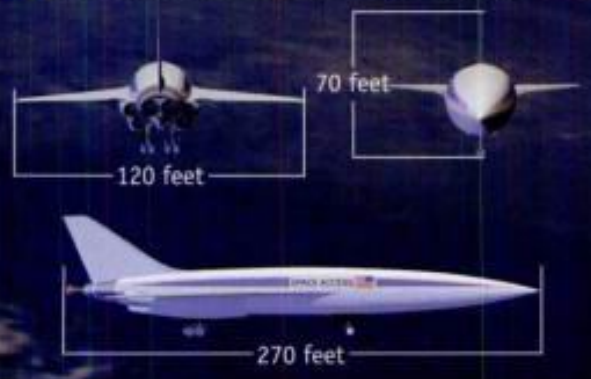


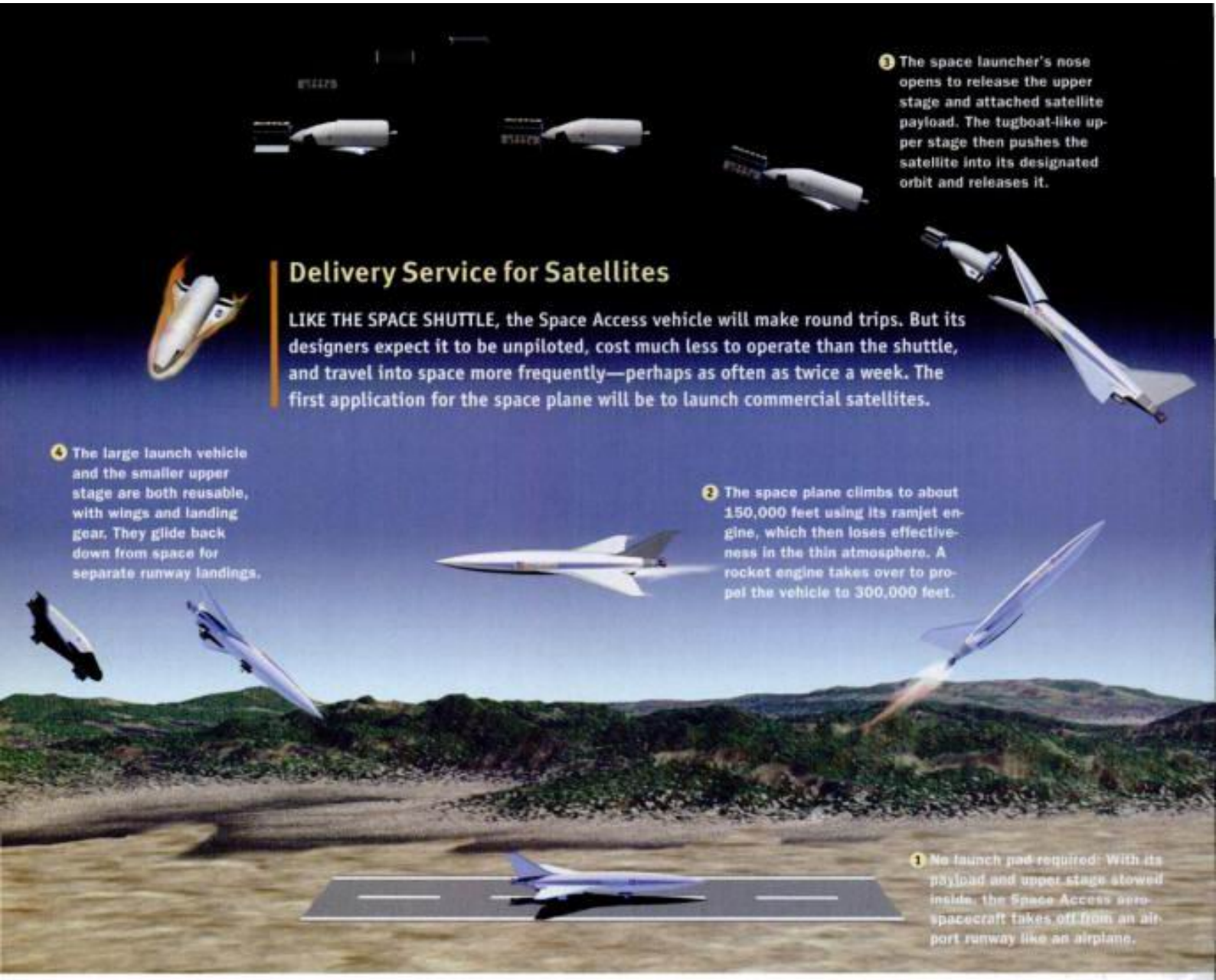
Open-and-Shut Mission

THE 747-SIZE SPACE ACCESS launcher disgorges a smaller winged craft to push a satellite into orbit. Dimensions shown are rough estimates.



AIRCRAFT ENGINES didn't change much in the 40 years after Orville and Wilbur Wright flew their first airplane. Air transportation, as we know it today, didn't happen until the jet engine arrived—making it possible to build aircraft that were much larger, faster, and more efficient than the old propeller-driven machines. Steven Wurst thinks that he and his colleagues have designed, built, and tested the engine that will do for space flight what the jet did for air travel. That is, the new engine will make it possible to transport cargo, and perhaps even passengers, straight from the runway to faraway destinations, day in and day out.

Wurst's company, Space Access, isn't the only one with plans to build a reusable launch vehicle that could deliver satellites and other payloads to orbit much more cheaply than today's spacecraft. At least four other private companies are working on reusable rockets ["Rocket Planes," Feb. '98]. And NASA is funding the development of a prototype for VentureStar, a rocket plane that could eventually replace the space shuttle. But Space Access claims it has something special: an engine that offers jet-like efficiency from a standstill to Mach 6. If so, the upstart company has overcome a problem that NASA



Delivery Service for Satellites

LIKE THE SPACE SHUTTLE, the Space Access vehicle will make round trips. But its designers expect it to be unpiloted, cost much less to operate than the shuttle, and travel into space more frequently—perhaps as often as twice a week. The first application for the space plane will be to launch commercial satellites.

and the rest of the U.S. space industry had not expected to solve for another decade.

Today's rockets are powered by engines that require liquid oxygen in addition to fuel, which means lugging heavy oxygen tanks along for the trip. But the ramjet engine built by Space Access "breathes" oxygen from the air, so the whole spacecraft weighs less and costs less to launch. "Air-breathing rocket engine technologies have the potential of opening the space frontier to ordinary folks," says Uwe Hueter, manager of NASA's Advanced Reusable Technologies project at the Marshall Space Flight Center.

Before 2005, Space Access plans to build a ramjet-powered aerospacecraft as big as a Boeing 747. It will take off from a runway and fly to just above the edge of the atmosphere, where it will release an upper-stage rocket that will push a satellite into orbit. If the payload is headed for an even higher geostationary orbit, 22,000 miles above Earth, a second, smaller rocket will provide an extra kick. The giant aerospacecraft and the two smaller rockets will all return and land like airplanes.

The Space Access system is designed to launch a 5-ton satellite into geostationary orbit, matching the payload capacity of today's biggest rockets. It will be built to the same standards of strength and reliability as an airplane, so that it will be able to fly once or twice a week, year in and year out. The United States, Europe, Russia, China, and Japan launched 70 rockets and shuttles last year; one or two reusable vehicles could replace them all.

It currently costs almost $10,000 to put a pound of payload into low Earth orbit. Space Access and its competitors are aiming to do the same thing for only $1,000 a pound. With launch costs reduced by 90 percent, Space Access could eat the lucrative satellite-launch business for breakfast, and handle NASA's space station launches for lunch. Dessert? Because the proposed vehicle flies like an airplane, it could offer a global same-day package service.

Building a brand-new spacecraft isn't cheap, of course. But Space Access has joined forces with Donaldson, Lufkin and Jenrette, a Wall Street merchant bank with billions of dollars in assets and a track record of finan-

NEWSFRONTS

SCIENCE & TECHNOLOGY

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BALLOONS

Floating to Victory

RIVAL BALLOONISTS had their hopes partially deflated this spring when Swiss psychiatrist Bertrand Piccard and British balloon instructor Brian Jones took their place in history as the first men to circle the globe in a balloon.

Launched from Cháteâu d'Oex in the Swiss Alps on March 1, the *Breitling Orbiter* 3 balloon effortlessly headed toward Morocco over Mauritiana, and then turned northeast to catch a jet stream—high-altitude winds that usually flow from west to east. Balloon pilots generally "steer" their balloons by rising or dropping to catch different jet streams. *Orbiter* 3 got lucky; the balloon sped toward India at 60 mph, and in the home stretch caught a 100-mph jet stream over the Atlantic to float to victory in Southeast Egypt. The feat took 20 days.

The trip was not without a few glitches. *Orbiter* 3 lost contact with mission control for four days while over the Pacific Ocean, and a broken heater dropped the cabin temperature to a chilly 46°F. And as the balloon crossed the Atlantic, its fuel levels dropped dangerously low. But the problems were relatively minor considering that just a week earlier competitors Andy Elson and Colin Prescot plunged into the Pacific after their balloon *Cable & Wireless* was ripped apart by a thunderstorm.

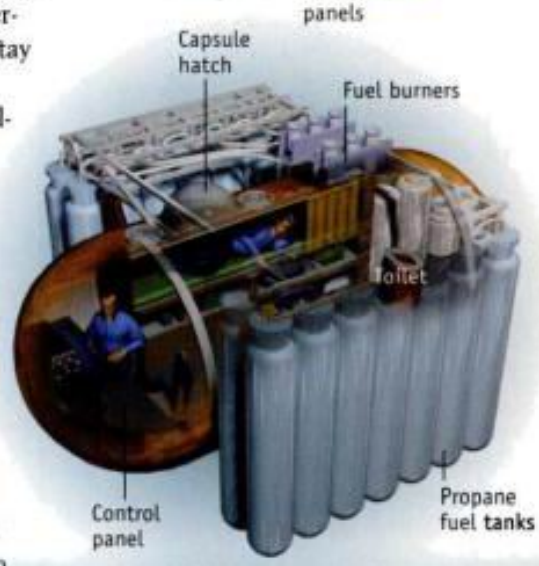
Since 1981, there have been more than 20 attempts to circle the globe in a balloon, and *Orbiter* 3's triumph isn't likely to stem the tide. There are still records to be broken. "The altitude record for a manned balloon is 113,000 feet," says Dave Liniger of Team Re/Max, a group planning to launch with two pilots later this year ["3 Men, a Balloon, and Their Quest for a Place in History," Jan.]. "We will break this record on the first day by climbing to 130,000 feet." *Orbiter* 3, by contrast, reached only 39,000 feet, but it did set distance and duration records. Liniger thinks that future balloonists might attempt to traverse even greater distances with higher-tech equipment and attempt to stay aloft even longer.

"We want to prove the technology of stratospheric ballooning even if we don't break any records," Liniger adds. "We will be conducting a civilian adventure into near space with several valuable scientific experiments, including reporting live to millions of people."

Meanwhile, rival balloonist and British recording-industry tycoon Richard Branson has said his new ambition is to sponsor an around-the-world balloon race, with his company, Virgin Group, footing the bill.—*Gunjan Sinha*

Orbiter 3

THE HUGE craft is really three balloons in one. Hot air keeps a shrinking helium cell aloft at night. A smaller helium cell holds up a tent that helps conserve heat.



During their 20-day voyage, the two pilots took turns sleeping in the single bunk of the pressurized capsule.

DON FLOEY

Shadow in the Shallows

The Navy's next nuclear sub will lurk stealthily offshore, using advanced sensors and weaponry to attack targets on land.

By Frank Vizard

ONE COMMAND YOU'LL never hear on America's next class of nuclear attack submarines is, "Up periscope." The reason is simple: The U.S.S. *Virginia*—which will be the first—and its brethren don't have any. The captains of these 21st century undersea boats will view the world through a digital video camera with better resolution than the human eye.

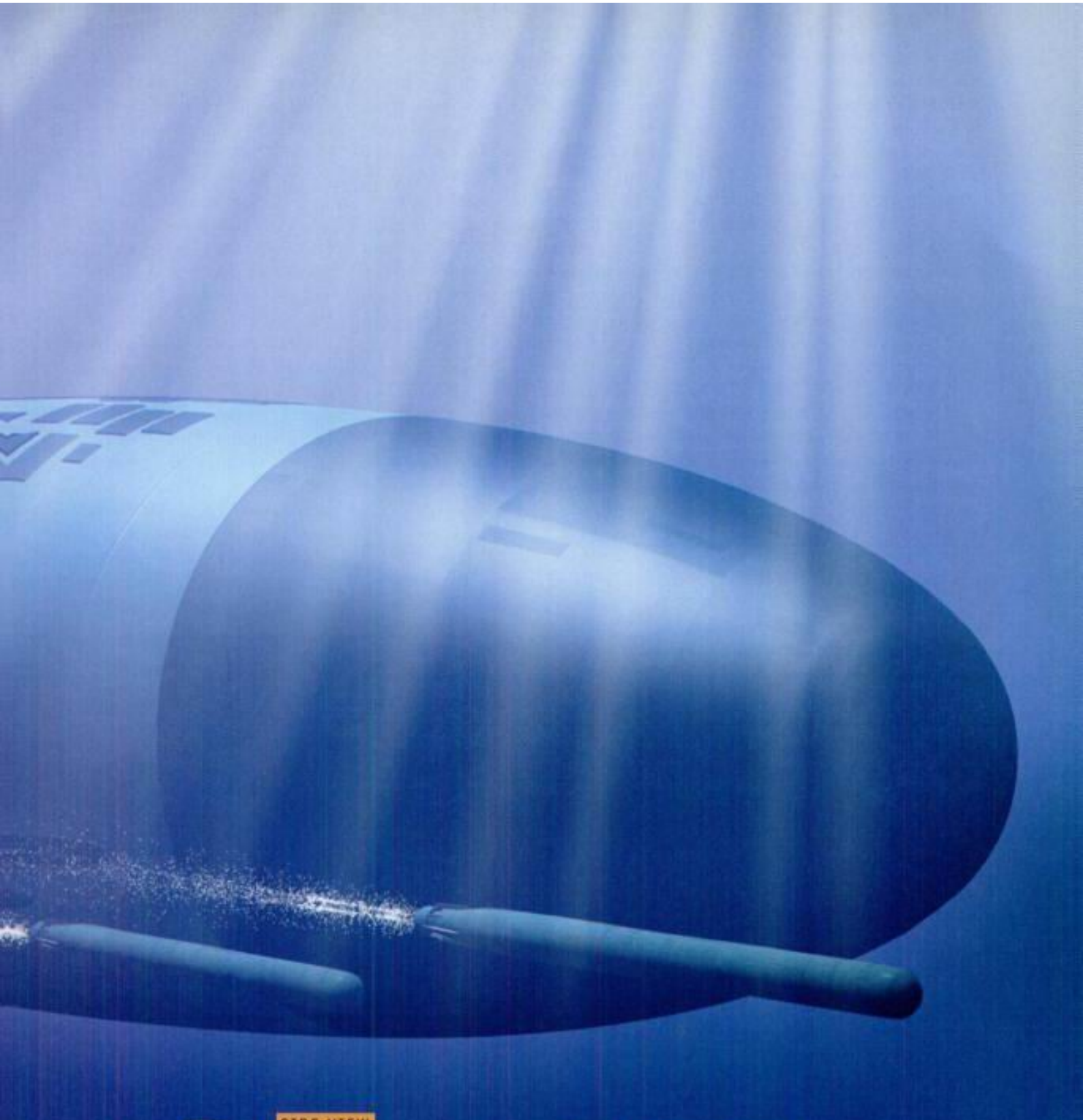
And that's just for starters. The boats also feature massive computing power, a near-silent drive system, vertically fired cruise missiles, and a modular construction for easy technology upgrades. The mission is new as well, emphasizing coastal operations over deep ocean patrols.

For the moment, however, the *Virginia* is in pieces in builder Electric Boat's shipyard in Quonset Point, Rhode Island. The pieces—or more accurately, the sections of the boat—won't be welded together for some years yet. But merely seeing these cylindrical sections, each the size of a three-story townhouse, is tangible evidence of new thinking about submarines in the post-cold war era.

While Navy submarine designers are still mindful of front-line Russian nuclear subs like the 10,000-ton *Severodvinsk* now under construction, the collapse of the Soviet Union and the rise of regional conflicts is creating the need for a new kind of sub. Perhaps most

ILLUSTRATIONS BY VIEWPOINT/MIKE SPEIGNER

Материал, защищенный авторским правом



The 7,700-ton USS *Virginia* attack submarine bristles with torpedoes and Tomahawk missiles. Vertical tubes, seen here as small squares near the bow, make launching missiles in shallow water easier.

tellingly, the *Virginia* won't have the ability to break through the polar ice on Russia's northern coast.

Gone are the days when American submarines existed principally to track their Soviet counterparts through the ocean. In the 21st century, the U.S. Navy sees its fast-attack submarines as "shadows in shallow water." They'll operate primarily in the "brown water" region between the coast and the end of the continental shelf, while the big 18,750-ton ballistic missile *Trident*-class submarines conduct "blue water" patrols in the open sea.

When the *Virginia* is commissioned in 2004, its mission will be to intercede more heavily in land hostilities than its fast-attack predecessors have. To this end, the *Virginia* will be equipped with a wide array of electronic sensors for intelligence gathering; pack a punch that includes 12 vertical launching tubes for Tomahawk cruise missiles; and be able to quickly deploy a six-man SEAL commando squad on their own minisub. The vertically launched cruise missiles make for easier firing from shallow waters. An adversary also has less time to react to sub-fired terrain-hugging missiles than against those fired from surface ships offshore.

"When you don't want your Tomahawks shot down, a submarine is the best platform to shoot from," says Capt. Paul E. Sullivan, the Navy officer in charge of developing the *Virginia*.

While the *Virginia* and other members of its class may dominate the 21st century waters numerically—the Navy ultimately hopes to launch 30—these submarines are not the best fast-attack boats they've ever put to sea. That distinction, if measured in terms of size, firepower, speed, and depth capabilities, belongs to the *Seawolf*, commissioned in 1997. The ice-breaking *Seawolf*, along with its sister ships, the *Connecticut* and *Jimmy Carter*, is characterized by a 40-foot-diameter hull displacing 9,100 tons along its 353-foot length. The Navy routinely declines to provide depth and speed data for its submarines, but independent sources estimate that the *Seawolf* can plunge to 2,000 feet and move underwater at speeds of up to 30 knots.

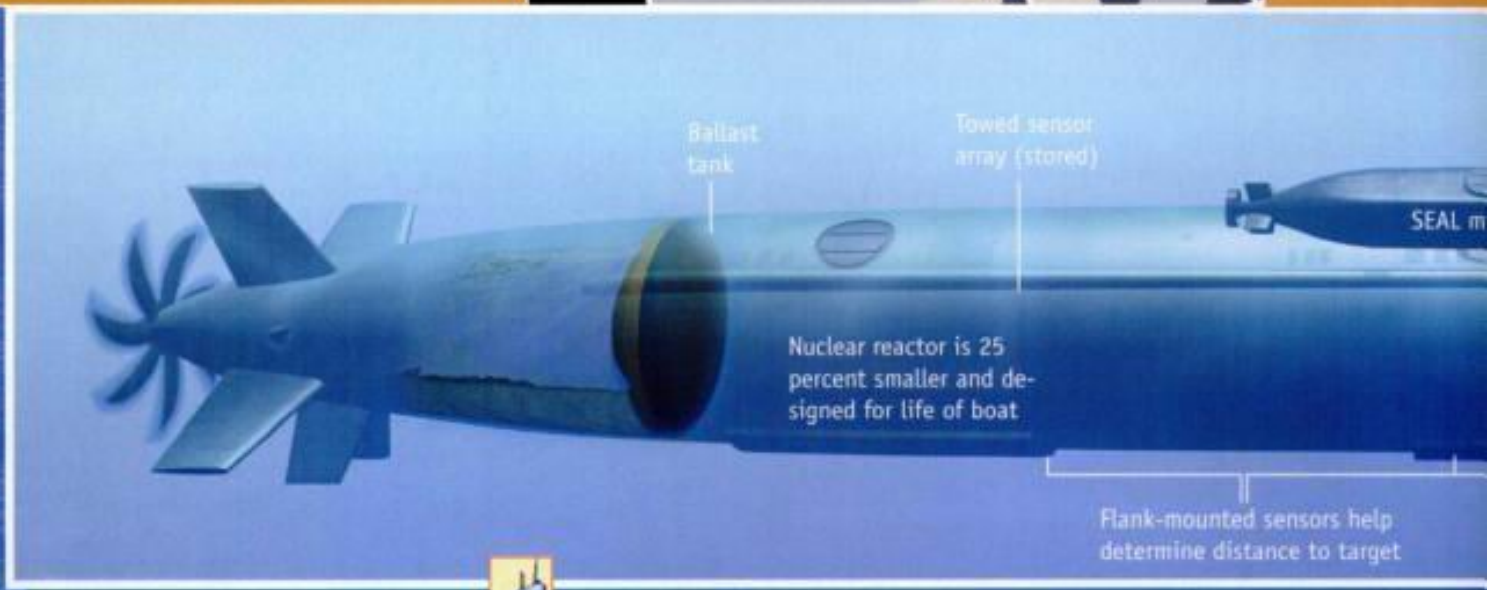
While the *Virginia* is a longer boat at 377 feet, it's smaller in diameter at 34 feet. The *Virginia* has only four torpedo tubes to the *Seawolf*'s eight, a shortfall compensated for by the *Virginia*'s vertical missile-launching tubes. The *Virginia* can also deploy torpedo-tube-launched unmanned underwater vehicles, primarily for laying and detecting mines.

The Navy admits that the *Virginia* is slower and can't submerge as deeply as the *Seawolf* but insists these shortcomings are not a big concern. "When we started the *Virginia* design, we said this ship has to be cheaper than the *Seawolf*, so we were willing to trade away some characteristics," explains Sullivan, who was also the Navy program manager for the *Seawolf*. "We ran mission-analysis studies to see what we could trade away and not give up mission

Stealth Along the Coast

WHEN THE USS *VIRGINIA* debuts in 2004, it will have advanced capabilities to help it operate in coastal waters around the globe.

The larger control room on the second deck includes (1) sub drivers with joysticks and touch-sensitive screens, (2) sonar, (3) an electronic chart for plotting targets, (4) a photonics and navigation station, (5) combat-control stations, (6) a special operations station, and (7) a radio room.



capability. What we found is that the ability of the *Seawolf* to dive deeper is tactically not very significant. It's not as important as how fast you can go and still stay quiet and hear with your sensors." While the exact numbers are classified, independent sources believe *Virginia* will have a speed of between 24 and 27 knots and will be able to submerge to about 1,700 feet.

The big problem with the *Seawolf* is its cost: $2.3 billion each. While the *Virginia*, as the first boat out of the yard, will sport a hefty $2 billion price tag, the cost of succeeding boats will decline, says the Navy. The fifth boat in the class will cost an estimated $1.6 billion. So far, only four *Virginia*-class boats have been approved for construction, alternately by Electric Boat and another shipbuilder, Virginia-based Newport News, through 2002, with commissioning for the fourth scheduled for 2008.

The *Virginia* class is designed to replace the current *Los Angeles* and 688 attack boats. In the absence of a perceived threat like that once posed by Soviet subs, the pace of construction is likely to be about one boat per year—a schedule that is more about keeping nuclear-submarine-building expertise alive than responding to an immediate national security need.

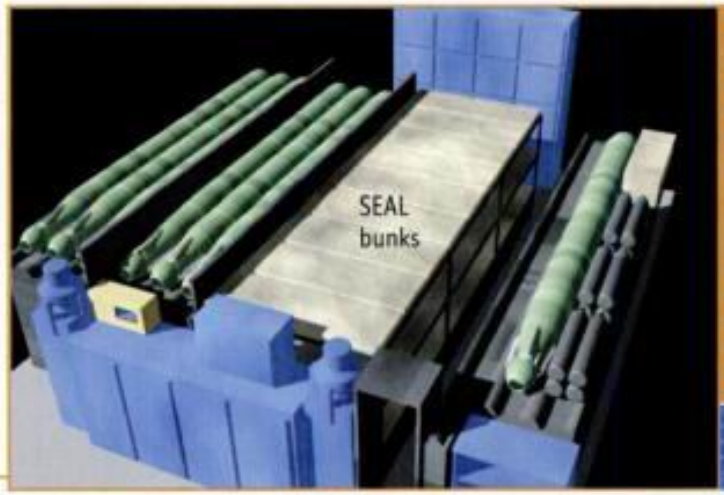
The *Virginia*-class boats will be cheaper to build, says the Navy, because of changes in the construction process and the use of off-the-shelf commercial technology. In the old days, building a submarine entailed working within a large tube—"like trying to build a watch through the stem hole," says Fred Harris, Electric Boat vice president and *Virginia* program manager.

Instead, the builders of the *Virginia* developed a modular approach. The sub is divided into sections to be welded together. Within each section, elements like the control center and the torpedo room are constructed separately and then fitted into the submarine after testing. The modules also provide better overall shock absorption, because they are more isolated from the hull. Making the job easier is the ability to design the entire submarine by computer, the first time this has ever been done.

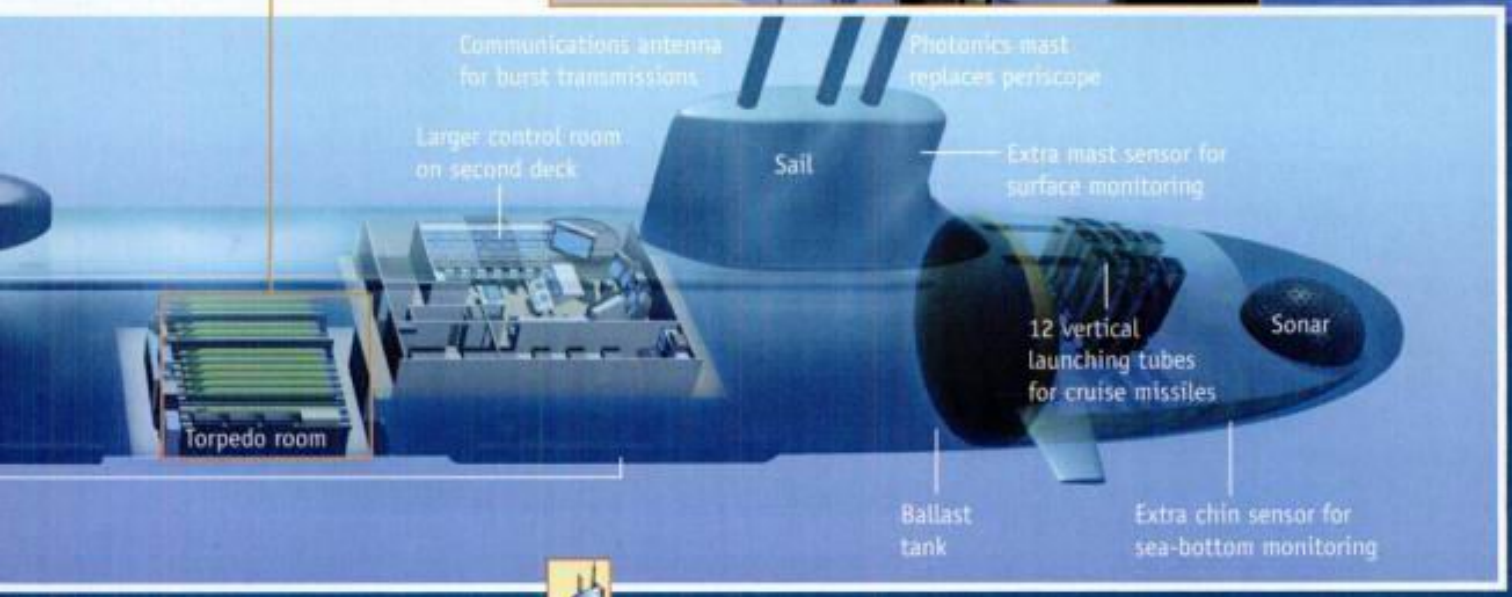
The modules give the *Virginia* lots of flexibility, both now and in the future for technological upgrades. For example, most of the torpedoes in the torpedo room can be quickly removed from their cradles to berth a six-man SEAL special forces team. The commandos can also get aboard their own 55-ton minisub, which has a range of 125 nautical miles. The new minisub is planned to be built by February 2000.

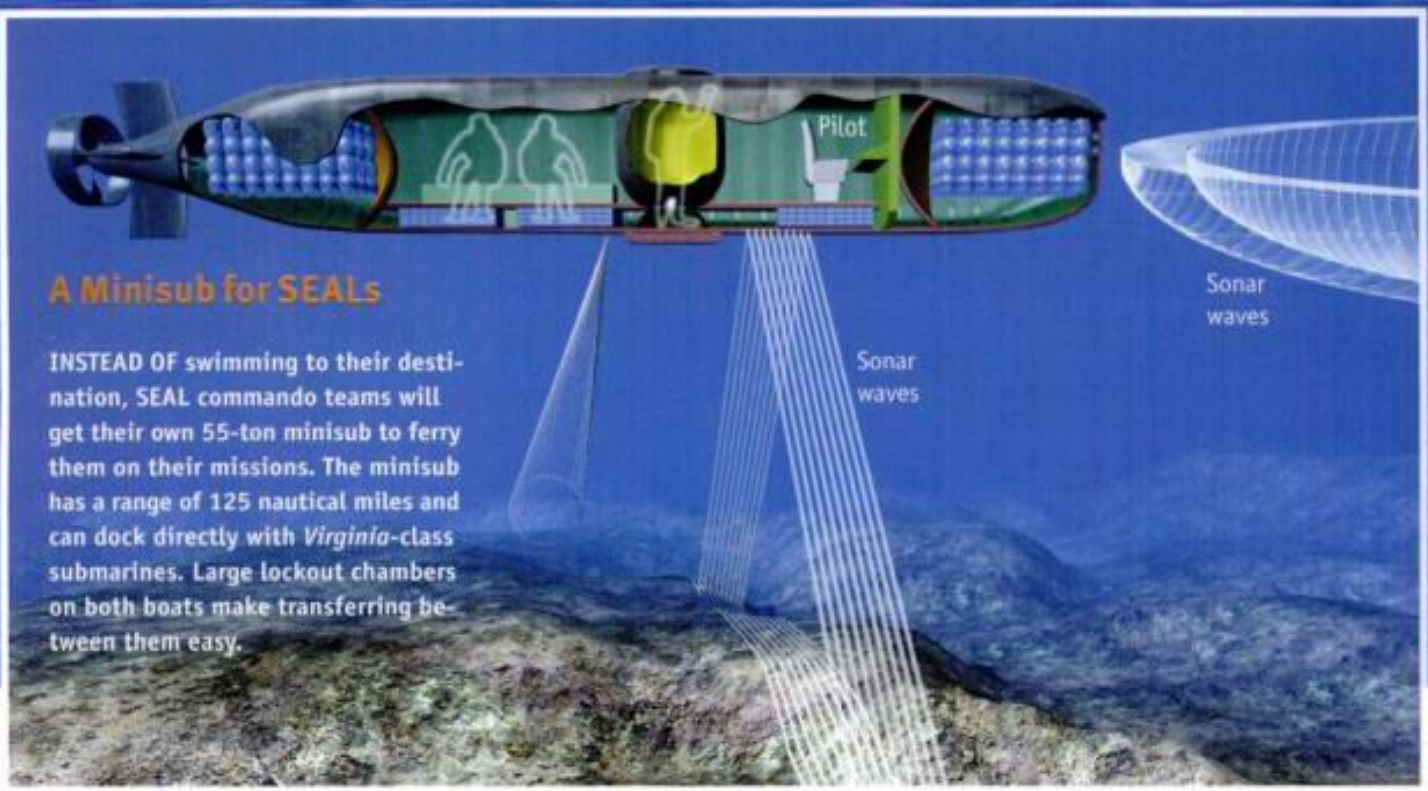
The SEAL minisub piggybacks the *Virginia* with plenty of room to spare, because the mother craft's upright "sail" is farther forward than on previous submarines. This position, along with the six fins on the stern, gives the sub driver an extra measure of control in turns. That makes the *Virginia* more maneuverable in shallow water than its length might suggest. The pilot and copilot will use joysticks rather than traditional yokes to drive the sub. These joysticks are linked to a computerized fly-by-wire like that used in many cars. Touchscreen displays give access to other control functions.

The pilots sit in what looks like a corporate computer center. In the past, the positioning of the periscope dictated the control room location. With



The torpedo room can be reconfigured to house a SEAL commando team and their gear. The torpedoes are removed from their cradles to create the needed space (left), leaving a small number for defensive use.





A Minisub for SEALs

INSTEAD OF swimming to their destination, SEAL commando teams will get their own 55-ton minisub to ferry them on their missions. The minisub has a range of 125 nautical miles and can dock directly with *Virginia*-class submarines. Large lockout chambers on both boats make transferring between them easy.

no periscope onboard, the control room can be moved from the top deck to the wider second deck. The fiber-optic photonics mast, as the video viewing system is called, has color, black and white, and infrared modes. Sonar operators, formerly situated in separate operations rooms, now sit in the control room for faster and better communication.

Not surprisingly, given advances in computer technology, the *Virginia* packs more computing power than the 65 *Los Angeles*- and *Seawolf*-class subs combined. The most advantageous application of this massive computing power is a new electronic chart that automatically processes sensor data to plot not only a bearing or direction for an undersea target, but also the distance involved.

Calculating the distance of a target wasn't possible on previous subs, because sound waves change as they pass through varying layers of water temperature. This new capability is particularly useful in shallow waters, where the noise of otherwise easily detectable diesel submarines used by other nations can be masked by background sounds from surface ships in high-traffic areas and reflections from the ocean floor.

Extra sensors under its chin and in its sail add to the *Virginia*'s detection capability. These extra sensors, complemented by an array along the sub's flank and another, towed array that trails behind, help the computer triangulate a target to determine distance. Location data is also provided by GPS navigation satellites in space and independent shipboard navigation systems.

Computer automation has reduced the portion of the 134-member crew needed for each watch. In addition, computers are used to digitally compress communications so that telltale transmissions are reduced to very short bursts. The Navy, however, is still working on the optimum method for integrating the "silent service" into an increasingly network-centric fleet that is constantly in communication.

Off-the-shelf technology includes a York air-conditioning system, and a reverse-osmosis unit with filtering membranes from DuPont that converts seawater to 4,000 gallons of fresh water per day.

One component that is definitely not an off-the-shelf item is the propulsion system, the most secret part of the *Virginia*. The nuclear reactor is 25 percent smaller and uses fewer parts than the *Seawolf*, making it much quieter. The reactor is also designed to last the life of the ship, about 33 years. Other submarines generally require at least one reactor refueling, a process that costs millions of dollars.

"The key to going fast quietly is the propeller," says Sullivan. On this subject the Navy is extremely tight-lipped, invoking the "If I tell you, I'll have to kill you" rule. Silence, of course, is the name of the game in submarine warfare, and while the propeller and the reactor are major factors, nearly every component is of concern on a boat considered to be relatively small in diameter, and therefore containing less material to dampen sound.

Sullivan maintains that the acoustic signature of the *Virginia* is as stealthy as that of the *Seawolf* and its non-acoustic signature—meaning the electromagnetic readings from cables and the magnetic anomalies generated by the hull—is even better disguised by techniques such as shielding and cable positioning. To put that in some sort of context, the *Seawolf* under way is described as being quieter than a *Los Angeles*-class submarine tied to a pier.

Operating undetected in hostile waters is a submarine's main mission, of course. But the U.S.S. *Virginia*, with its mix of intelligence-gathering capability and striking power, brings that mission closer to the beach than ever before.

Материал, защищенный авторским правом

HOW BLAST WAVES AMBUSH THE BRAIN

It's not just flying shrapnel and brute force that cause concussions on the battlefield. Pressure waves may also play a role. Here's how

Points of injury

Primary blast wave

Pressure waves

Blood vessels

An explosion begins with a powerful pulse of hot compressed gas that radiates outward, generating a wave of pressure that can travel up to 1,500 mph. The bigger the bomb, the faster and more forceful the wave. A vacuum of air trails this initial wave, creating a violent suction force that can shear organs.

But little is known about how blast waves damage the brain. Shock waves rattle the head but may also compress the torso, transferring energy to blood vessels. One theory is that the oscillating waves travel through the bloodstream and into the brain, where they twist and kill neurons over time.

▲ **STRETCHED TO THE LIMIT** Shock waves can damage healthy brain cells. Sometimes just lightly twisting the cell is enough to do the job.

▲ **THE DOWNWARD SPIRAL** The shearing not only causes physical damage to cells but can also unleash a biochemical cascade that eventually causes cells to self-destruct.

Материал, защищенный авторским правом

Suitable Alternatives

Which design will 21st century astronauts wear to the space station and beyond? NASA will borrow from both.

By Christopher Miller

WITH DEMANDING SPACE missions planned into the next millennium, what will the well-dressed astronaut of 2005 be wearing? One idea recently delivered to NASA suggests a look akin to the body of the classic TV "Lost in Space" robot, with a huge Slinky cinching the waist. But whatever next-generation space suits look like, one thing is certain: Their lighter weight and increased mobility will bring new freedoms and capabilities to astronauts.

To understand why space suits are bulky and heavy, consider the difficulties of shielding fragile human life in the harshness of space. Temperatures can reach 250°F in the sun or minus 250°F in shadow.

Astronauts' gloves, for instance, must be thick enough to protect hands but not so thick that spacewalkers can't manipulate objects. In the vacuum of space, suits must be pressurized to 4.3 pounds per square inch—equivalent to about 34,500 feet in altitude. The consequence: Spacewalkers have to fight their suits just to move around, increasing fatigue.

"You're basically in your own personal spaceship," says Gregory Harbaugh, a former astronaut who now heads NASA's EVA (for Extra Vehicular Activity, which includes spacewalks)

ILLUSTRATIONS BY DON FOLEY

Clark Gloves

For a better fit, the next gloves for astronauts will be designed for individual crew members, using laser-scanning techniques. Future gloves may even be power-assisted, to avoid the fatigue from fighting a pressurized space suit during long walks outside spacecraft.

Suiting Up for the Future

WITH SPACE MISSIONS planned into the next century, NASA needs space suits that are up to the challenge of lengthy spacewalks for the space station—or perhaps even on other planets. To meet increasing performance demands, suits will have to be lighter and more flexible. Two companies, David Clark and ILC, have delivered prototypes offering new-tech solutions.

DAVID CLARK SUIT

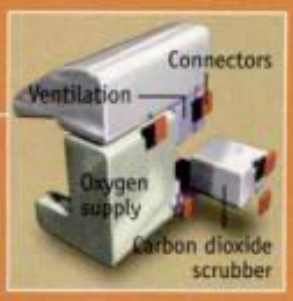
WITH ITS suit, David Clark Co. sought to provide mobility without a lot of weighty bearings. The suit will be similar to the one shuttle astronauts wear while riding into space, but with several additions and modifications to the joints. Tucked fabric and Slinky-like toroidal joints in the knee and hips are flexible without being heavy, letting the new suit weigh in at a mere 26 pounds.

Helmet

Advanced communication systems will be integrated into the helmet—foregoing the current separate "Snoopy cap." To deliver visual information, a retinal or head-up display, as well as a TV monitor, could be incorporated into the helmet.

Computer

To clear the front of the suit of obstructions so that working in space is easier, NASA plans to move all controls to a computer mounted on the astronaut's wrist or arm. Controls will have to be enlarged to compensate for the lack of dexterity in the gloves.



Life Support

NASA is considering three design ideas as replacements for the current Portable Life Support System—the backpack astronauts wear during spacewalks. In the first, parts plug into a "motherboard." A second fits parts into foam molding. The last, a modular design (shown), fashions life-support components into compartments that astronauts can easily replace in the event of a malfunction. Included in these designs will be a new carbon dioxide scrubber, oxygen delivery system, and thermal ventilation.

M-SUIT

ILC DOVER'S design goal was a lighter, more flexible, and mobile version of NASA's current spacewalk suit. ILC removed the hard, fiberglass upper torso to shed weight: The new suit weighs 60 pounds (minus life support)—half that of today's suits. Ten joint bearings add mobility, allowing an astronaut to more easily kneel on one knee and examine a rock.

M-Suit Gloves

Missions to the space station will use gloves with more gimbals and double ballasts than previous gloves, allowing more natural wrist movement. Result: increased dexterity and less astronaut fatigue.

Boots

Astronauts on today's space shuttle missions don't have to stomp around on a planet surface, so their boots are extremely rigid. But if space travelers are to walk on the surfaces of other worlds someday, the boot soles will have to be more pliable—similar to a hiking boot.

Prodded by a visionary outsider,

Manned Mission to Mars

By Paul Raeburn

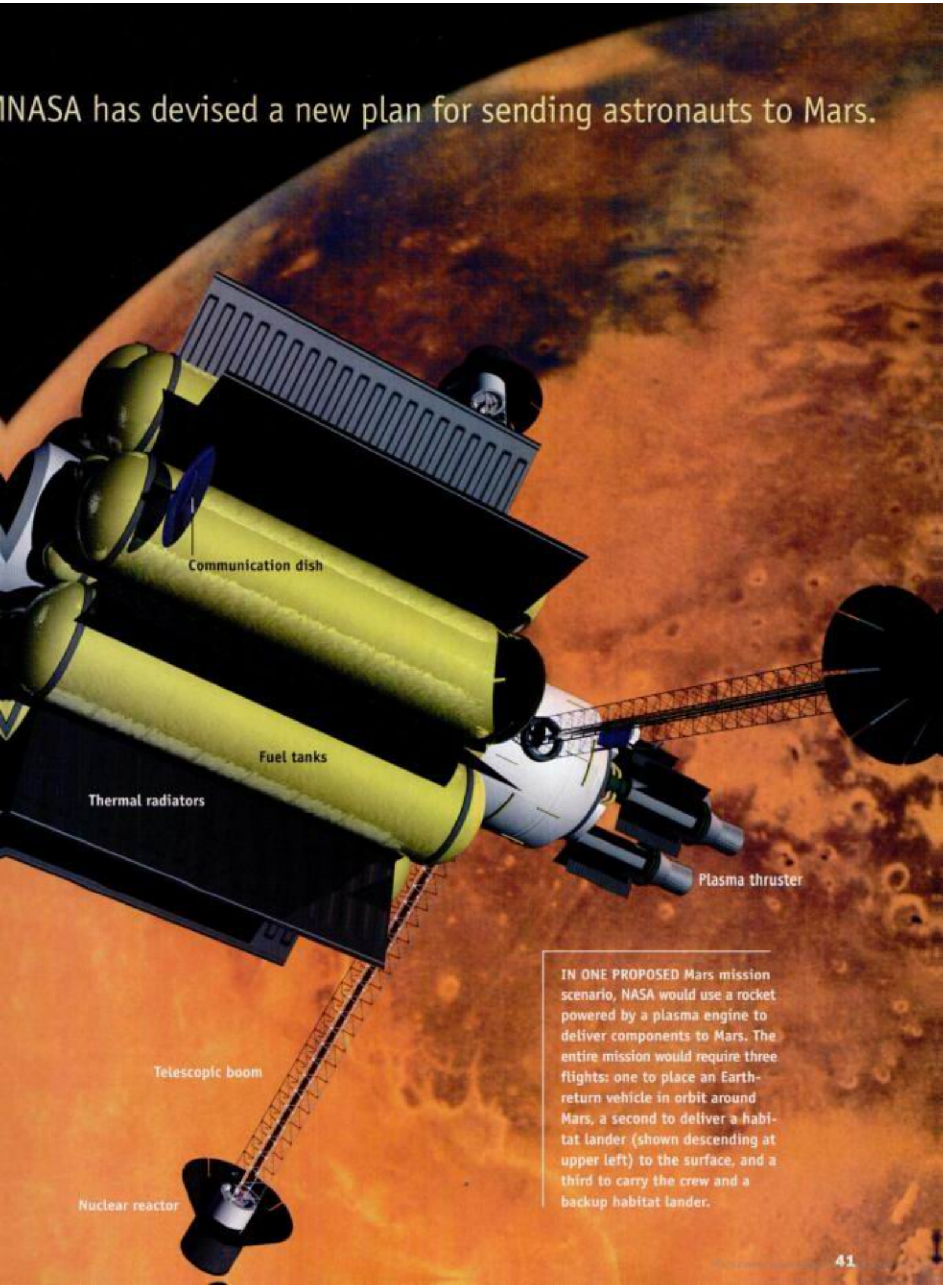
IN HIS OFFICE at the Jet Propulsion Laboratory in Pasadena, California, physicist Mark Adler holds a transparency up to the light. He points to a timeline laying out NASA's ambitious program for the exploration of Mars. The timeline shows missions that will be sent to study the martian soil and atmosphere, to analyze rock samples, and even to bring rocks back to Earth. Then Adler points to the year 2014. There the timeline ends with a stunning climax: a human mission to Mars.

Nearly three decades after landing on the moon, NASA is once again devoting serious study to human spaceflight beyond Earth's orbit. This time, the most likely target is Mars. The costs of a two-and-a-half-year human mission to Mars, once estimated to be in the hundreds of billions of dollars, have now fallen to as low as $20 billion, or about $2 billion per year for 10 years. That fits well within NASA's budget constraints; the agency now spends that much on the International Space Station. And the most recent feasibility studies from NASA's Johnson Space Center in Houston suggest that Adler's timeline may be too pessimistic. JSC engineers are now saying they can deliver astronauts to Mars in less than a decade.

"We're laying the groundwork," says Adler, the architect of JPL's program to explore Mars with robots in advance of human exploration. NASA, which waited 21 years after the 1976 Viking mission to go back to the surface of Mars with Pathfinder, has now set up a Mars assembly line. While Pathfinder's rover was scurrying over the martian surface, engineers were already planning the Mars 98 mission. Missions are also planned for the next launch opportunities in 2001 and 2003. (Fuel requirements are lowest if spacecraft are launched when Earth and Mars are nearest each other; such "opposi-

ILLUSTRATIONS BY BOB SAULS/JOHN FRASSANITO & ASSOCIATES

NASA has devised a new plan for sending astronauts to Mars.



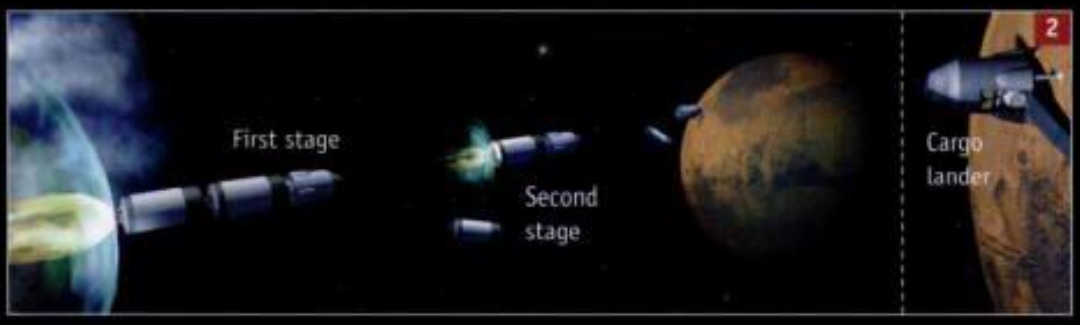
IN ONE PROPOSED Mars mission scenario, NASA would use a rocket powered by a plasma engine to deliver components to Mars. The entire mission would require three flights: one to place an Earth-return vehicle in orbit around Mars, a second to deliver a habitat lander (shown descending at upper left) to the surface, and a third to carry the crew and a backup habitat lander.

For each flight, three stages are launched separately into low Earth orbit and assembled there. The crew arrives in a shuttle before the final flight departs.

NASA REFERENCE MISSION

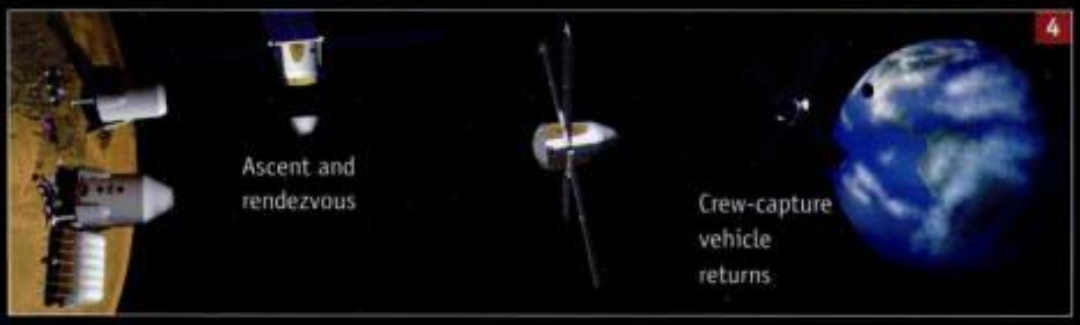
THE STANDARD AGAINST which future proposals for Mars exploration will be measured, NASA's Reference Mission calls for three flights that would deliver a crew of six astronauts to the surface of Mars for a 500-day stay. NASA engineers currently estimate the cost of the mission could be as low as $20 billion.

On the first flight, an Earth-return vehicle (ERV) is placed in orbit around Mars. It is delivered fully fueled, and remains in orbit for nearly four years, until the first crew is ready to come back to Earth.



Shortly after the ERV is launched, a cargo lander is sent to the surface of Mars. It contains an unfueled ascent vehicle, a propellant production plant, liquid hydrogen, a nuclear power plant, and an inflatable habitat.

Once the ERV and cargo lander have arrived and been tested, and the lander has produced sufficient fuel for the ascent vehicle, the crew arrives in a second lander and installs the inflatable habitat.



After spending about 500 days exploring Mars, the crew uses the ascent vehicle to rendezvous with the ERV in Mars orbit. The return trip ends with a direct entry; the crew lands in a capture vehicle using a steerable parafoil.

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MARS DIRECT

TO SAVE TIME AND MONEY, the Mars Direct plan would send components straight to the surface of Mars, without stopping to orbit Earth or Mars. This approach requires a much smaller crew capsule, and a crew of four astronauts rather than six.

The first flight sends an unmanned Earth-return vehicle to the surface of Mars aboard Ares, a launch vehicle derived from the space shuttle. The ERV begins making fuel for the trip home.

While traveling to Mars, the lander is joined to the spent Ares upper stage by a 1,500-meter-long tether. They spin at one rpm to create an artificial gravity equivalent to that of Mars.

A second ERV lands automatically, providing a backup vehicle in case the first one malfunctions. The ERV carries a nuclear reactor that supplies power for making fuel, water, and oxygen.

The first crew departs in the original ERV, and a second crew arrives in a new lander. The tether and spent upper stage are released before the lander touches down on the surface of Mars.

A third ERV is sent to the surface as a backup. If the second ERV is functioning properly, the second crew uses it to return home, leaving behind both crew landers for future visitors.

Материал, защищенный авторским правом

Cutting Edge Engines

NASA IS DEVELOPING a variety of advanced rocket-propulsion systems, some of which might be used in human Mars missions. Here are the most promising alternatives to conventional chemical rockets:

SOLAR-ELECTRIC PROPULSION Electricity generated by solar cells is used to ionize atoms of xenon or krypton. The electrically charged ions are accelerated through an electromagnetic field and expelled, generating thrust in the opposite direction. Ion propulsion has already been used to keep an Earth-orbiting satellite in position, and to power the Deep Space 1 probe launched a few months ago.

NUCLEAR ELECTRIC Similar to solar-electric propulsion, but electricity is generated by a nuclear reactor.

PLASMA An ion engine with an afterburner, in which radio waves or other means are used to add energy to the ions. They are then compressed to form a plasma before being expelled. Plasma engines produce higher thrusts but consume more power.

NUCLEAR THERMAL Hydrogen is heated by a nuclear power source to nearly 5,000°F and expelled at supersonic speeds from a nozzle.—*P.R.*

payload is only about 20 metric tons, but when it's loaded, the weight of the orbiter is about 80 metric tons. "You can think about replacing the orbiter with payload, and you essentially have a system in place that can almost do what we want to do."

This new launch vehicle is referred to as the Magnum. Like the space shuttle, the Magnum would have a large fuel tank with two attached booster rockets. But in place of the shuttle orbiter would be a long cylinder mounted atop the fuel tank. That cylinder would house the elements of the Mars mission.

The Magnum would put the components of the Mars mission into low Earth orbit, comparable to the orbits the shuttle flies. There they would be assembled in preparation for the trip to Mars. In one scenario, the finished package would not go straight to Mars. Instead, NASA would use a space "tug" to slowly haul each Mars payload into a much higher Earth orbit. From there, it takes only a small additional kick to get the payloads on their way to Mars.

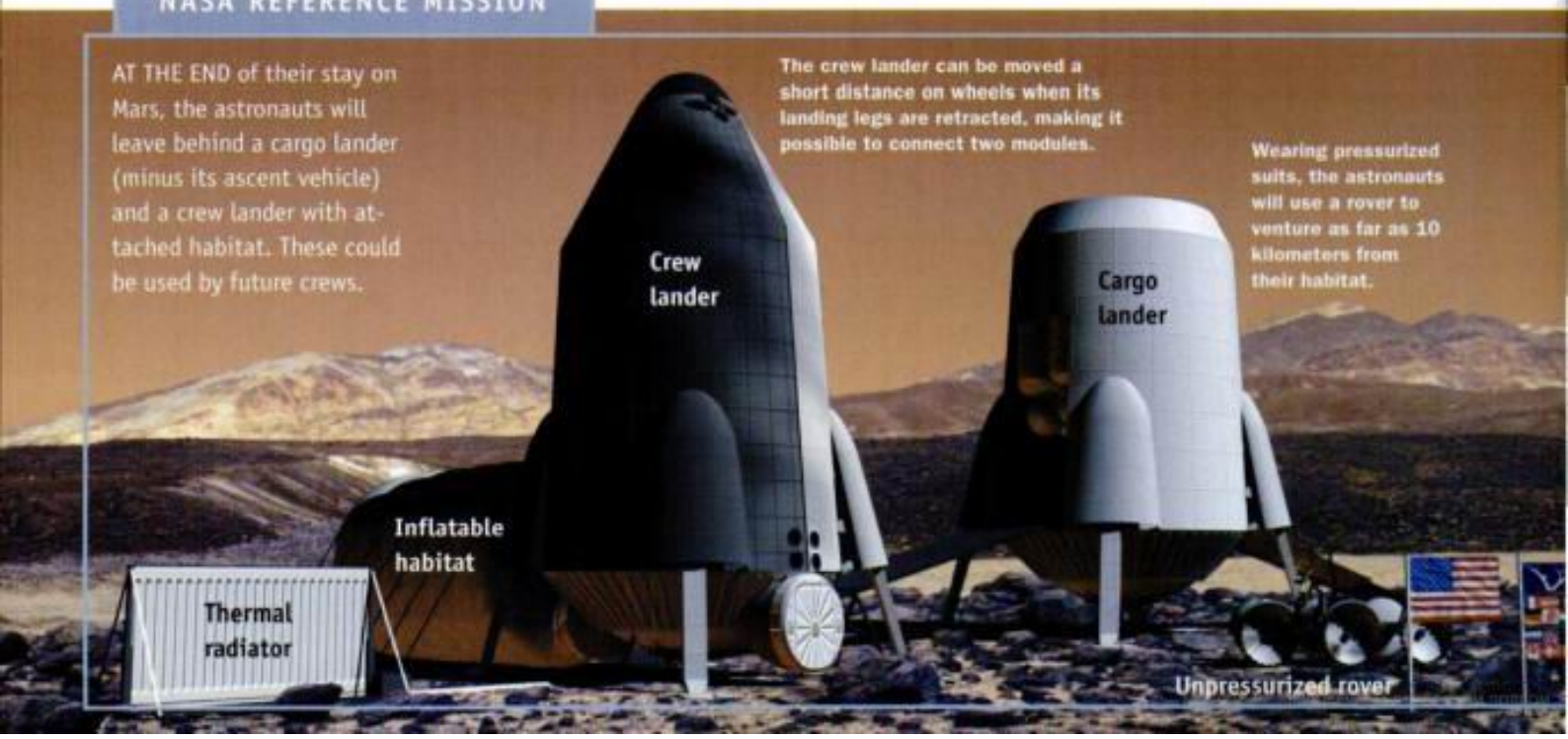
The details of the space tug design are constantly being updated. **The latest plan envisions a spacecraft with a solar-electric ion engine,** but NASA is also considering chemical, nuclear electric, nuclear thermal, and plasma propulsion systems.

Once the space tug takes the payloads into high Earth orbit, it will disconnect and lower itself back to pick up another payload. The payloads in high Earth orbit will be sent on their way to Mars with a short burst from a conventional chemical rocket.

The principal advantage of ion engines is that they're very efficient, but they don't provide a lot of thrust. The trip from low to high Earth orbit takes about six months. That's fine for the unmanned payloads, but what about the astronauts? Once the payload with their second habitat has reached high orbit, "You shoot the crew up there quickly in a smaller system," says Joosten. "It's sort of like the dinghy that goes back and forth to the big ship moored offshore."

Zubrin is not in favor of using advanced propulsion systems such as solar-ion engines for the early Mars missions, because he is afraid that the development of such systems could delay the overall mission. Columbus, Zubrin notes, did not wait to develop trans-Atlantic sailing vessels before wandering off in search of a new world. "Once he did that—once people knew there was some place to go—then you

NASA REFERENCE MISSION



had the development of three-masted frigates and steamships and ocean liners and Boeing 747s. Destinations drive transportation."

Zubrin's Mars Direct mission is smaller and lighter than NASA's. He has in mind a crew of four, not six. He would begin in 2005 with the launch of a vehicle similar to the Magnum. It would carry an Earth-return vehicle directly to the surface of Mars, without stopping to orbit Earth. A direct flight, Zubrin says, would eliminate the need for a space tug or any other additional hardware in orbit.

Zubrin's mission saves weight by using a smaller habitat, one that NASA believes is too small. "You can't put them in an Apollo-size capsule for six months," says Joosten. NASA's mission calls for a larger capsule, one that is too heavy for a direct mission.

In Zubrin's plan, a second Earth-return vehicle would be sent to Mars two years after the first one. As with NASA's mission, this would serve as a backup, or it could be used by the second crew sent to Mars. A few weeks after the second Earth-return vehicle is launched, a crew of four would be sent to Mars, again by a direct flight from Earth to the surface of Mars. After 500 days or so on the surface, the crew, using propellant produced on Mars, would fly directly back to Earth, without stopping to orbit Mars.

Zubrin's mission requires only two launches, while NASA's requires three. That makes NASA's inherently more expensive. And, as Zubrin points out, NASA's plan depends upon a "mission-critical" rendezvous in Mars orbit. On the other hand, Zubrin's mission requires that far more fuel be made on the surface—enough to get the astronauts home, not just into Mars orbit.

While most of the technology to get to Mars is in hand, some important challenges remain. "We really want to get a lot of information back from the space station," says Bret Drake, who leads the human mission study at JSC's Exploration Office. "How the body adapts to zero gravity is one of the main things." Life-support systems and other technology can also be tested aboard the space station.

NASA isn't waiting for the completion of the station to begin its studies, however. The plans for a human Mars mission will advance beyond the design stage in only two years, with the launch of the Mars 2001 mission. The unmanned spacecraft will carry a small-scale version of the propellant-production system.

On the unmanned mission that is planned for 2003, NASA is considering studies that will explore the possibility of "air capture." NASA wants to find out if it can put a spacecraft into orbit around Mars by using the friction of the atmosphere to slow it down, rather than a rocket burst. Air capture would reduce the amount of fuel needed for a martian mission.

NASA might also use the 2003 mission to produce methane on the surface and to test schemes for more precise landings. Pathfinder was designed to land somewhere within a 300-kilometer "error ellipse." With a human mission, the error ellipse will need to be no longer than about 3 kilometers, Drake says.

Zubrin will also be busy preparing for the future. Working with the newly formed Mars Society, he hopes to raise $1 million for the construction of a Mars habitat module in the Canadian Arctic. "We want to have that up and running by 2000. If we can do that, we can raise perhaps $5 million to $10 million to fly a hitchhiker payload to Mars by 2003," he says, perhaps on a planned European Mars probe. One idea for the payload is a balloon-mounted camera that would drift through the martian atmosphere and send back a bird's-eye view of the planet. Zubrin's group eventually hopes to raise enough money to fly a robotic mission of its own to Mars.

Nearly 30 years after the first moon landing, it now seems that interplanetary exploration has once again become a real possibility. "It's definitely going to happen," says Drake. "It's just a matter of time."

MARS DIRECT

AFTER TWO SETS of astronauts have come and gone, a pair of crew landers and an Earth return vehicle will remain on the surface of Mars. As with the NASA plan, components left behind become spares for future crews.

The Big Picture

A cluster of giant telescopes may help astronomers find distant new worlds.

By Erin Cassin

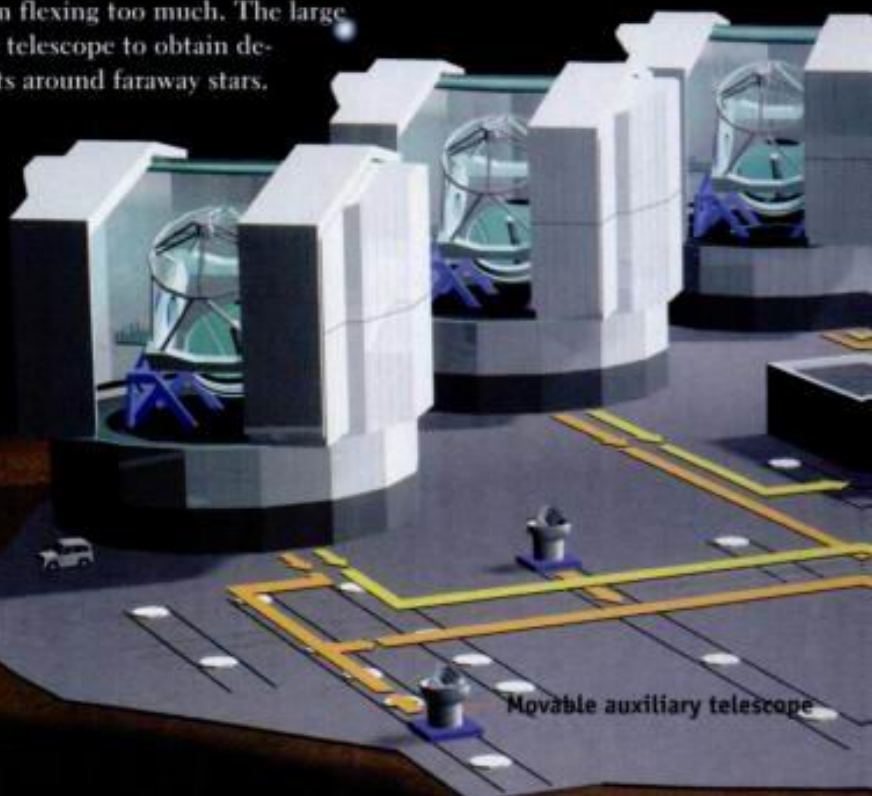
THE WORLD'S LARGEST OPTICAL TELESCOPE array, scheduled for completion around 2003, is already producing useful images. When finished, the European Southern Observatory's Very Large Telescope (VLT) will consist of four large telescopes and three smaller ones that work in unison. The first of these telescopes to be constructed generated more than 200 images during its moments of "first light" at the Paranal summit in Chile a few months ago.

The pictures demonstrate that the VLT is measuring up to its design goals: producing high-quality images while retaining the ability to discern distant objects undetectable by smaller telescopes. "That's the beauty of this telescope," says Richard West, an astronomer at the observatory.

At the heart of each of the four large individual telescopes is a thin, 25-foot-diameter mirror supported by computer-controlled pistons that continually adjust the mirror's shape and prevent it from flexing too much. The large surface area of the mirror should enable the telescope to obtain detailed images of faint objects, such as planets around faraway stars.

When all seven of the VLT telescopes are completed, they will have the combined light-gathering power of a 50-foot telescope, and an interferometric mode for high-resolution imaging. The VLT's design reflects a recent astronomical trend. "This is the era of big telescopes on the ground," says National Solar Observatory director Jacques Beckers, who worked on the VLT in the early 1990s. ▸

Stars in this strange galaxy in Centaurus are rotating in two different planes, which indicates the presence of dark matter within the system.

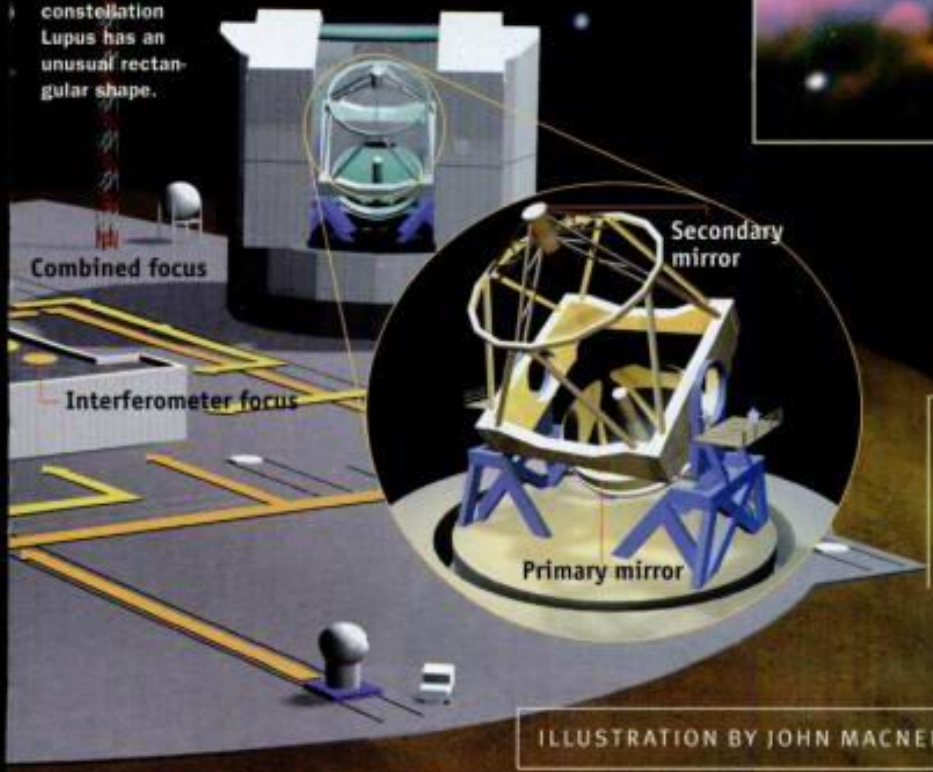


Movable auxiliary telescope

This planetary nebula in the constellation Lupus has an unusual rectangular shape.

EUROPEAN SOUTHERN OBSERVATORY

One of the first pictures taken by the new telescope shows the Butterfly Nebula: a shroud of gas that has been ejected and then irradiated by a massive, dying star.



In this interferometric array, seven individual telescopes are linked together to form a gigantic instrument called the Very Large Telescope. Each telescope focuses on the same celestial object, and computers combine the collected light to produce a composite image that reveals fine details.

ILLUSTRATION BY JOHN MACNEILL

Creatures of the Twilight Zone

To study the bizarre gelatinous carnivores that populate the ocean's midwaters, scientists are unleashing sophisticated new probes.

By Steve Nadis

ON A GRAY MORNING in early May, I embark with a team of scientists on the research vessel *Point Lobos*, headed for the deep waters of California's Monterey Bay. The target of the day's "fishing trip" is a strange group of animals with translucent, gelatinous bodies. Most have no brain, heart, lungs, eyes, or protective shell, and they can't make a sound. Yet they can sense light, find prey, navigate, and defend themselves.

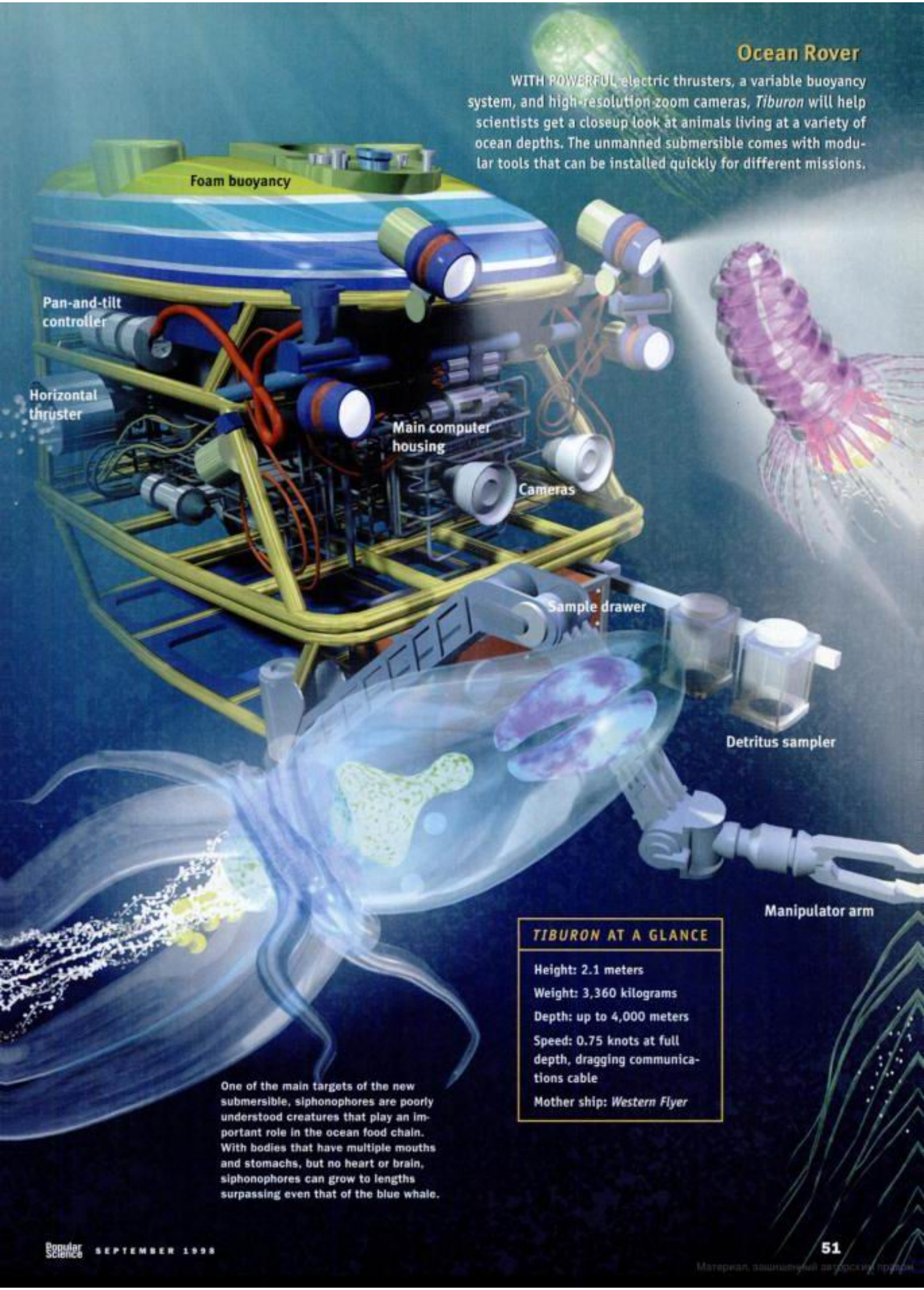
These creatures, called siphonophores, spend their lives adrift in the dark, boundless, three-dimensional world of the ocean's midwaters—a zone extending from about 100 meters below the surface to 100 meters above the seafloor. Wispy, chain-like carnivores that can outcompete bulkier predators such as shark and squid, siphonophores are composed of modular pieces—with multiple stomachs, tenta-

ILLUSTRATIONS BY DON FOLEY

Материал, защищенный авторским правом

Ocean Rover

WITH POWERFUL electric thrusters, a variable buoyancy system, and high-resolution zoom cameras, *Tiburon* will help scientists get a closeup look at animals living at a variety of ocean depths. The unmanned submersible comes with modular tools that can be installed quickly for different missions.



TIBURON AT A GLANCE

Height: 2.1 meters

Weight: 3,360 kilograms

Depth: up to 4,000 meters

Speed: 0.75 knots at full depth, dragging communications cable

Mother ship: *Western Flyer*

One of the main targets of the new submersible, siphonophores are poorly understood creatures that play an important role in the ocean food chain. With bodies that have multiple mouths and stomachs, but no heart or brain, siphonophores can grow to lengths surpassing even that of the blue whale.

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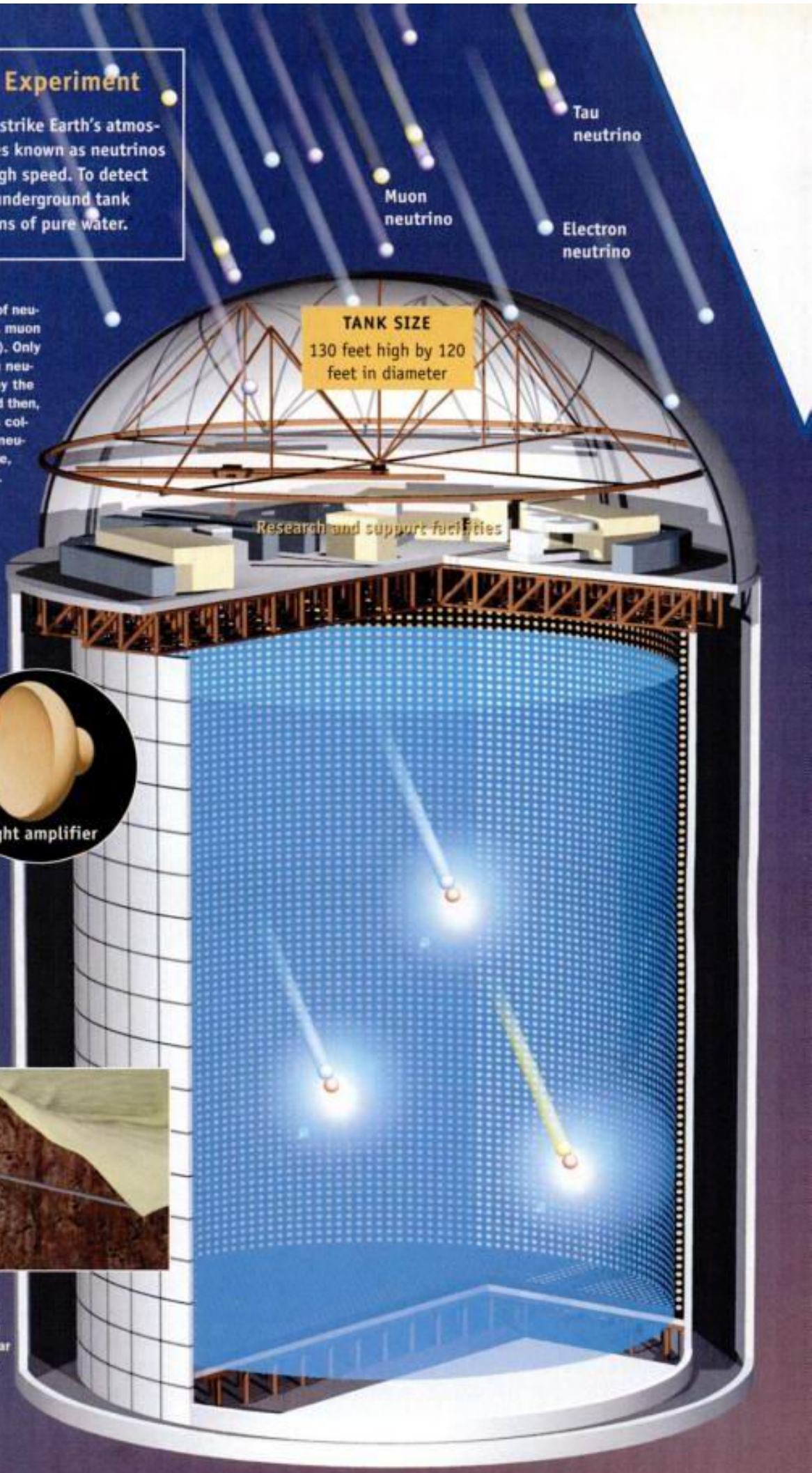
Super-Kamiokande Experiment

CREATED WHEN COSMIC RAYS strike Earth's atmosphere, the subatomic particles known as neutrinos pass through the planet at high speed. To detect them, physicists use a huge underground tank filled with 12.5 million gallons of pure water.



There are three types of neutrinos: electron (blue), muon (yellow), and tau (pink). Only the electron and muon neutrinos can be "seen" by the detector. Every now and then, one of these neutrinos collides with a proton or neutron in a water molecule, producing a blue flash.

Lining the tank are 11,146 light amplifiers, which detect the flashes. By analyzing each flash, researchers have learned that fewer muon neutrinos are passing through the tank than expected.

The results suggest that some of the muon neutrinos are oscillating, or turning into tau neutrinos, on their way through Earth. Neutrinos cannot change from one type to another unless they have mass.

To build the detector, workers dug a large, domed cavity more than 3,000 feet underground in a mine, beneath a mountain near the Japanese town of Kamioka.

The Phantom Particle

The discovery that neutrinos have mass could undo the laws of physics.

By Arthur Fisher

INFOGRAPHIC BY JOHN MACNEILL

AMONG THE many puzzles that plague cosmologists, perhaps the most vexing is this: What will be the universe's ultimate fate? Will it continue to expand forever, finally stabilize, or contract and end in a cataclysmic fireball?

The answer depends on the amount of matter, and thus gravitational attraction, in the universe. Not enough, and the universe will expand without end. Too much, and the world will end in what some astrophysicists call the Big Crunch.

Unfortunately, the amount of matter that is now visible isn't nearly enough to account for the behaviors astronomers have observed, such as the velocity of rotating galaxies. Calculations range wildly, but as much as 90 percent of the required mass may be "missing." Many bizarre particles have been theorized as supplying this missing mass, but none have been detected.

Enter the neutrino. It was first proposed by Wolfgang Pauli in 1930 as a desperate solution to a seeming impossibility having to do with a form of radioactive decay. To satisfy the requirements of quantum mechanics, the nameless particle had to be electrically neutral and totally free of mass. (It was eventually dubbed neutrino, meaning "little neutral one," by Enrico Fermi.) The phantom particle was not actually detected until 1956, by Frederick Reines and Clyde L. Cowan Jr.

A Brief History of the Neutrino OVER SIX DECADES, neutrinos have moved from theory to experimental proof.

1930 Wolfgang Pauli hypothesizes the existence of a massless particle to account for missing energy when neutrons decay. A year later Enrico Fermi names the particle a neutrino.

1956 Electron neutrinos discovered coming from a nuclear reactor.

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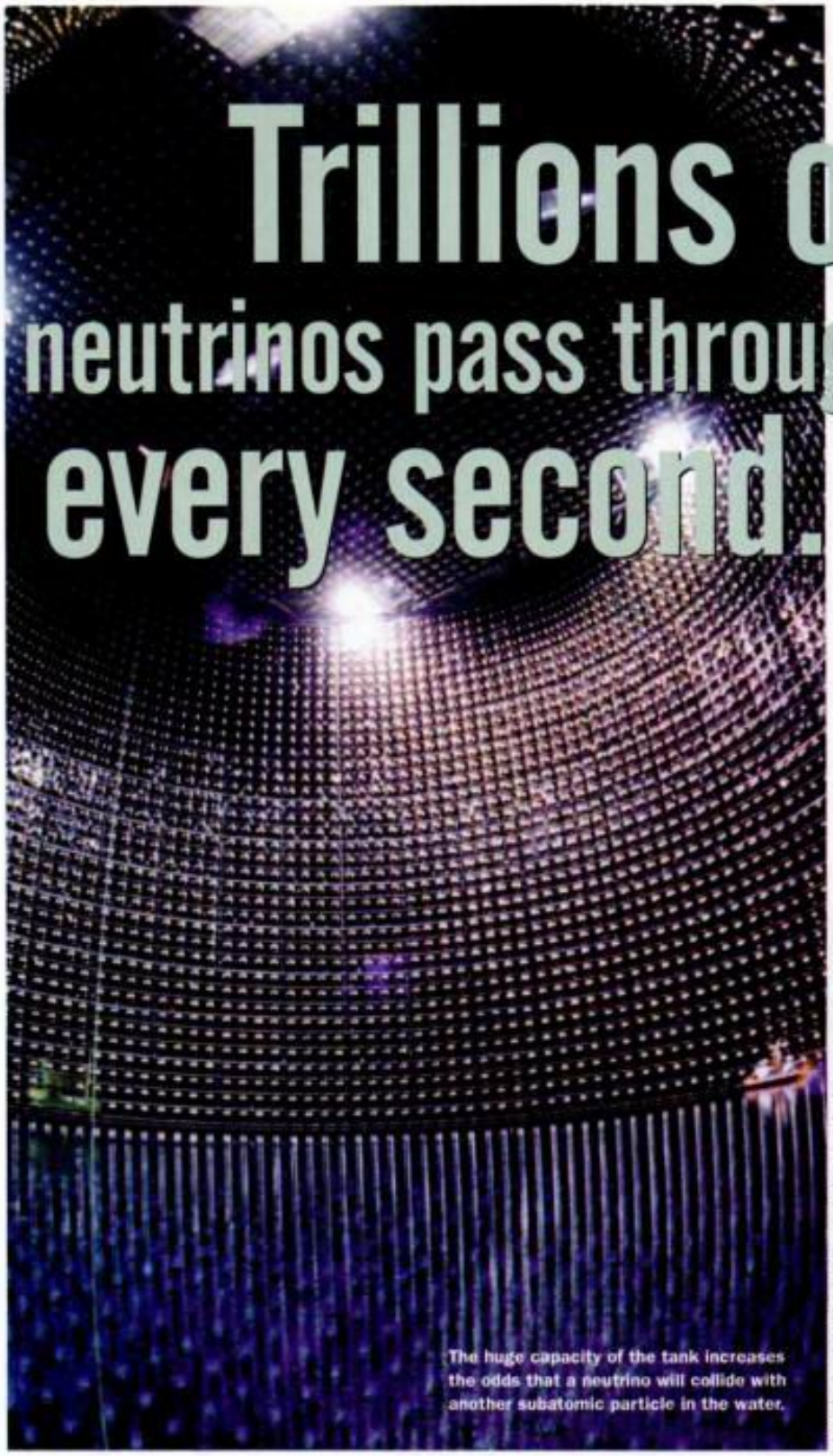
Not recreational boaters: Physicists check light amplifiers in the gigantic tank of the Super-Kamiokande detector.

Trillions of neutrinos pass through every second.



The huge capacity of the tank increases the odds that a neutrino will collide with another subatomic particle in the water.

In the past 20 years or so, particle physicists trying to accommodate increasingly elaborate theories of matter have suggested that neutrinos might indeed have some mass. To test the idea, experimenters have built detectors in deep underground mines in Canada, Italy, Japan, Russia, and the United States; at the South Pole under thousands of feet of ice; and under the deep waters of Lake Baikal in Siberia. Some of the experiments have provided indications of neutrinos with mass, but the measurements have been so borderline that they could not inspire confidence.

Until now.

What is apparently a clincher has been delivered by an experiment called Super-Kamiokande, located 3,000 feet deep in a zinc mine under the Japanese Alps about 125 miles west of Tokyo. The detector consists of a colossal stainless steel tank—130 feet high and 120 feet in diameter—filled with 12.5 million gallons of purified water and lined with 11,146 light amplifiers. Managed by a team of 120 physicists from 23 institutions in Japan and the United States, it is the largest neutrino detector ever built,

1961
Muon neutrinos are discovered at Brookhaven National Laboratory.

1957–62
Bruno Pontecorvo and Shoichi Sakata speculate independently that neutrinos oscillate between different types.

1965
The first naturally occurring neutrinos are observed in a South African gold mine.

Space Shuttle Orbiter

–ready for test flight

Riding piggyback on modified 747, Orbiter 101 will be carried aloft for its first test flights. Special tail cone will cover three rocket engines on some tests to reduce aerodynamic drag.

By JIM SCHEFTER

Struggling for altitude in the hot, thin desert air, its massive payload pressing down on its back, the modified Boeing 747 mother ship staggers to 24,000 feet. Explosive bolts blow with audible pops. The 747 lurches forward and down. Like a baby whale cast loose, Space Shuttle Orbiter 101 lifts away and is flying.

But "flying" may be too generous a term for what happens next. The pilots of the Orbiter, sinking at more than 10 feet per second, pull up the nose of their unpowered craft for a practice flare and "landing" at altitude. At 18,000 feet, less than a minute since free flight began, the maneuver ends. It's the

Launched from the 747 at 28,000 feet, the Orbiter will glide to an unpowered landing three to four minutes later—or less with tail cone off, as at top left. Middle left: Huge craft will be delivered by truck over back roads in the Mojave Desert from Palmdale, Calif., where it's being built, to Edwards Air Force Base, where tests will be done. Bottom left: Rear view of Orbiter shows rocket engines that will assist Orbiter's launch into space—around 1980. Below: Model of rear half of solid rocket booster is tested to see how hot it might become during its tumbling re-entry into the earth's atmosphere after the Orbiter is lifted into space. Differences in temperature—ranging from red hot to cool—are made visible by using materials whose ultraviolet radiation varies with temperature.

last chance the pilots have to feel out their machine before landing.

Banking left through a 180-degree turn, now plummeting at nearly 200 feet per second, the pilots lock on to the special microwave landing system installed on the 15,000-foot Mojave Desert runway. Onboard computers monitor every inch of the descent; a "fly-by-wire" avionics package that may be the most advanced in the world gives the pilots precision control down the glide path.

At 24 degrees, this glide path is eight times steeper than the slope used by commercial airliners. Screaming downhill toward the runway at 300 knots, the Orbiter is pulled into the final flare a mile out and 1900 feet up. At 500 feet the pilots drop the gear and pick up a normal three-degree glide path.

Seven seconds later, the Orbiter touches down at 175 knots. The pilots tap the toe brakes gently to affirm human command.

That flight profile, with variations from flight to flight, will be

Continued

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LOCKHEED/ERIC SCHULZINGER PHOTO

But six years from now, as *Freedom* takes shape 200 miles above the planet, the launch schedule is a lot looser. After eight or nine Shuttle flights, enough of the structure will be in orbit to allow what NASA terms man-tended capability. A Shuttle will berth at *Freedom*, and a crew will spend 13 to 16 days working aboard the Station, returning to the orbiter to eat and sleep.

The mod squad

Today, in an ongoing study at Johnson Space Center, a team of engineers is examining ways to extend a Shuttle's sojourn at *Freedom* to 30, 60 and even 90 days. Hardware modifications, "mods" in NASA lingo, are the focus. "The plan is to bite this thing off in small chunks," says Germany. "What we're looking at right now are mods we have to make to stay for 30 days. We'd like to achieve that capability in January 1997."

As it turns out, the EDO mods for which *Endeavour* is rigged could suffice for a 30-day stopover. The critical components aren't pieces of hardware but consumables—food, crew atmosphere, clothing and power.

During a more protracted rendezvous, however, the Shuttle's fragile mechanical systems will become points of vulnerability. "As we push this thing to stay up longer," says Germany, "we'll get into the possibility of breakage. It's those fluids and gases that you have to worry about: hydraulics, helium to purge systems, nitrogen to operate valves and so on."

But modernizing the 1970s-vintage anatomy of the Shuttle would require drastic surgery. Charged with keeping the fleet spaceworthy as cheaply as possible, NASA management has balked at forking out for expensive technological upgrades.

So far, the only major mod that has been approved for the Shuttle is the multifunction electronic display system, or MEDS—a glass cockpit that will soon replace the orbiter flight deck's electromechanical switches and dials.

"We're not actively pursuing any new technology unless it solves obsolescence," insists Nicholson. "That's the genesis of the MEDS cockpit. When we looked at failure rates of the display equipment, projecting into the late 1990s, we concluded that the old analog configuration could become a showstopper for us."

By opting away from other wholesale changes, Shuttle managers admit, they'll have to shell out more for vehicle repairs and life-support of an industrial base skilled in yesterday's technology. Still, says Nicholson, that's cheaper than gut-renovating the spacecraft.

The Next Generation

● When will NASA begin building a vehicle to replace the Shuttle? "My crystal ball's not clear enough to tell you," says Shuttle program director Leonard Nicholson. And spaceflight boss William Lenoir has made it clear that the question won't be considered for another five years. But that doesn't mean NASA hasn't laid the groundwork for a Shuttle follow-on.

At Langley Research Center's Vehicle Analysis Branch, engineers have been mulling options for an Advanced Manned Launch System (AMLS), ranging from 2-stage rocket vehicles to single-stage airbreathers.

Conclusions? They depend on whether designers play it safe with proven hardware or hold out for breakthrough technologies, such as those promised by the National Aero-Space Plane program. If near-term technology is assumed, then a winged 2-stage rocket system fits the bill. If advanced hardware proves itself, a single-stage vehicle would save money over the long haul.

AMLS rocket-powered options include (left to right): advanced 2-stager with cargo held internally, near-term 2-stager with external payload bay and advanced single-stager.

PM ILLUSTRATION BY ED VALIGURSKY

High-performance rockets appear best suited for simple payload delivery to orbit, while airbreathers could handle more complex—possibly military—missions that might demand orbital intercept, loitering or vehicle recall. The tradeoff for this flexibility is a more costly propulsion system and a heavier spacecraft.

For a simple Space Station rendezvous mission, which favors the rockets, AMLS designers factor in two new safety features: a jettisonable crew module and single-engine-out capability on each stage. The airbreathers, geared for performance, may have neither.

—G.T.P.

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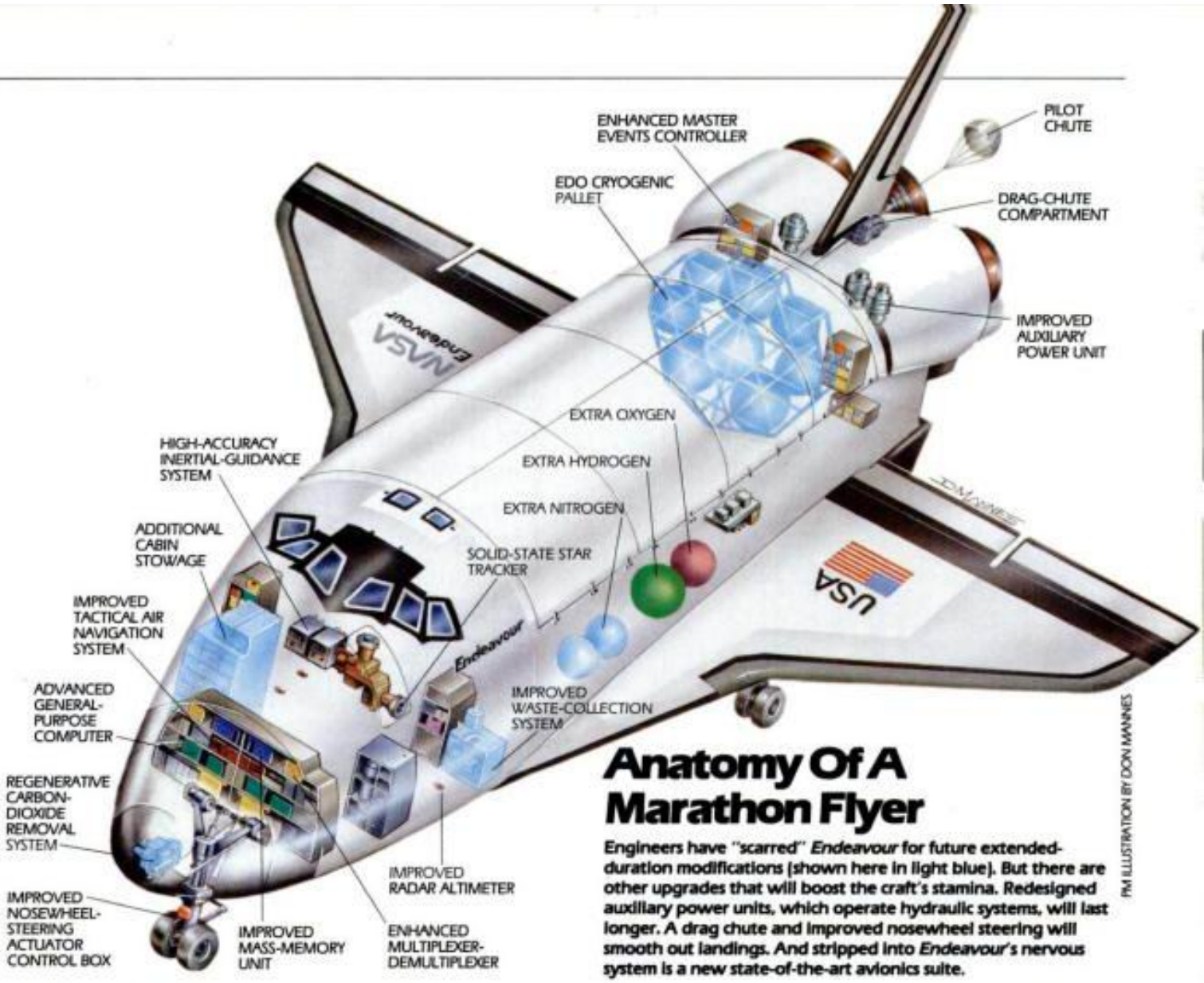

PM ILLUSTRATION BY DON MANNES

Anatomy Of A Marathon Flyer

Engineers have "scarred" *Endeavour* for future extended-duration modifications (shown here in light blue). But there are other upgrades that will boost the craft's stamina. Redesigned auxiliary power units, which operate hydraulic systems, will last longer. A drag chute and improved nosewheel steering will smooth out landings. And stripped into *Endeavour*'s nervous system is a new state-of-the-art avionics suite.

The human factor

Beyond stacking the odds on hardware breakdown, marathon missions will take their toll on the Shuttle's human cargo. For *Endeavour*'s first skipper, Cmdr. Brandenstein, prolonged space travel is nothing new. On his last trip into space, commanding *Columbia* in January 1990, the 49-year-old Navy pilot spent 11 days in orbit—then the longest Shuttle flight to date.

"We know you can adapt to zero-gravity very quickly and operate up there," says Brandenstein, who also happens to be chief of NASA's Astronaut Office. "But we have an uneasy feeling that there's a dropoff in your proficiency beyond 16 days."

The performance decay, officials fear, could erode the flight crew's ability to land the Shuttle safely. Not willing to gamble, William Lenoir, NASA's associate administrator for spaceflight, has ordered an automatic touchdown system called Autoland to bring in a Shuttle unassisted next year, possibly on *Endeavour*. The software has resided in every Shuttle cockpit since *Columbia*'s first flight, but it has never been tested out.

Astronauts bristle at the idea of relinquishing command of the Shuttle, especially during a maneuver that requires deft control and near-instinctive judgment calls. "It's a glider, remember, so you can't go around and try it again," Brandenstein argues. "We'd be more comfortable with a man in the loop from subsonic to touchdown."

Yet in the face of protracted missions, unmanned operations have drawn research attention. The concept appeals to engineers at NASA's Langley Research Center who have proposed the Personnel Launch System, a small winged spacecraft that would reach orbit on the nose of a heavy-lift rocket (see Tech Update, page 15, Jan. '91).

"It would be a lot cheaper to deliver the crew in a PLS," notes Langley's Ted Talay, "and by concentrating on unmanned delivery, you could boost payload capacity." According to a separate Rockwell study, by stuffing the crew compartment with cryogenic tanks, avionics and fuel cells, the payload bay could stretch to swallow an extra 15,000 pounds.

But with NASA steering a conservative course for the Shuttle, the remote-control orbiter could remain a paper spacecraft. Instead, look for *Endeavour* and the rest of the fleet to continue shuttling men and women into space.

Dress rehearsals for space-station activities, in particular, will need the human touch. After kicking a stray Intelsat satellite into its proper orbit, *Endeavour*'s first flight crew will practice space-station assembly techniques in the longest series of spacewalks ever attempted from a Shuttle.

As NASA gears up for a taste of *Freedom*, a performance machine like the Space Shuttle *Endeavour* will take on a heavy workload. And with no other man-rated spacecraft in sight, NASA's brand-new baby must lead its older siblings into the 21st century. **PM**

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NEWSFRONTS

HOME TECHNOLOGY

EDITED BY JUDITH ANNE GUNTHER

BUILDING TECHNOLOGY

A Cubist's Idea of Home

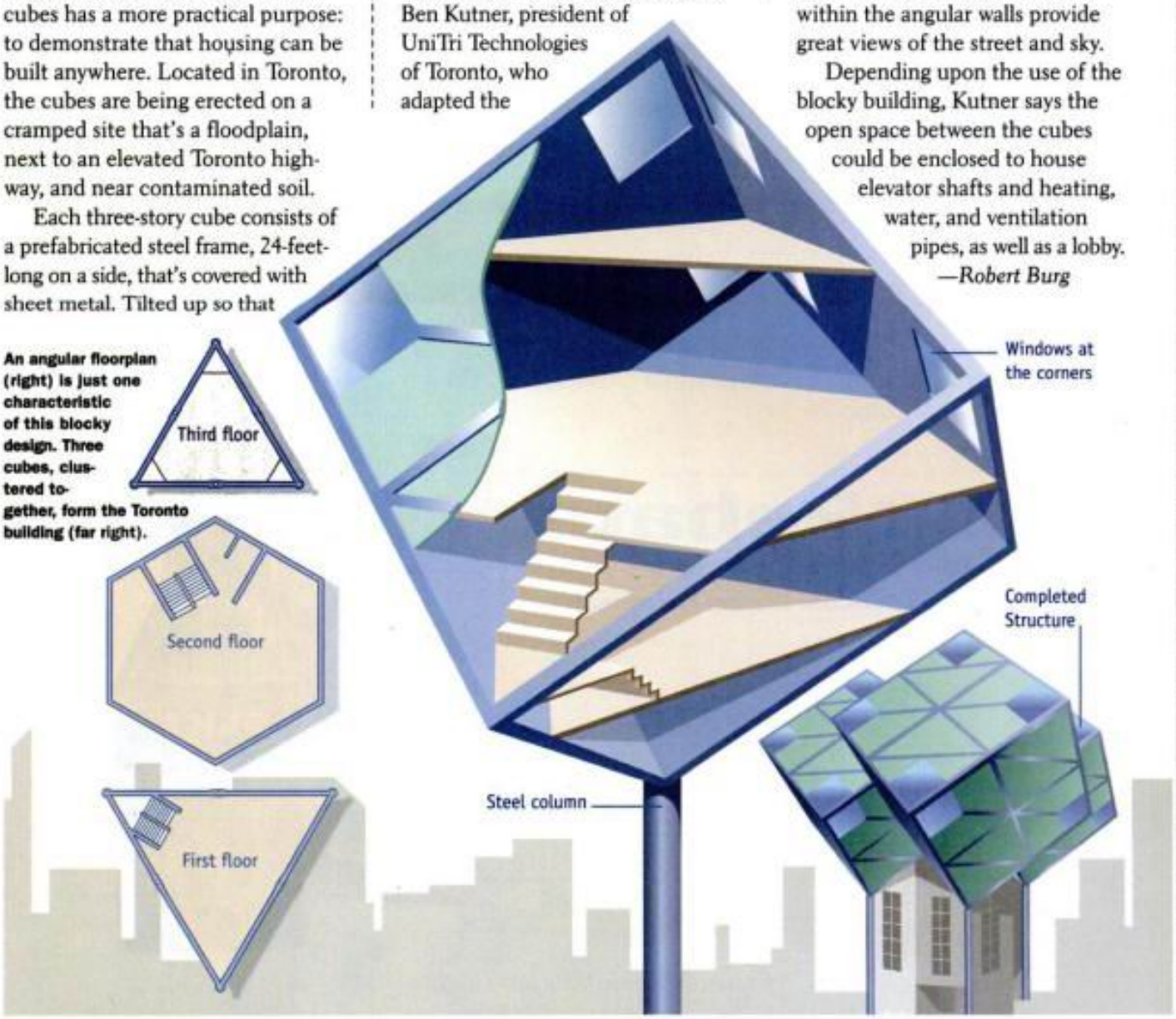
YOU MIGHT mistake it for modern sculpture, but a trio of giant steel cubes has a more practical purpose: to demonstrate that housing can be built anywhere. Located in Toronto, the cubes are being erected on a cramped site that's a floodplain, next to an elevated Toronto highway, and near contaminated soil.

Each three-story cube consists of a prefabricated steel frame, 24-feet-long on a side, that's covered with sheet metal. Tilted up so that one corner points skyward, each cube rests on a 18-foot-tall steel column. This elevated building concept can make use of small, environmentally challenged urban lots that are traditionally spurned by developers, says Ben Kutner, president of UniTri Technologies of Toronto, who adapted the design from a Dutch building.

The unique design also uses building materials efficiently. For instance, who needs a peaked roof for shedding rainwater when the structure already is sloped? Because the cubes are bolted together for additional support, a large foundation isn't necessary: Instead, the steel columns extend approximately four feet into the soil. And windows within the angular walls provide great views of the street and sky.

Depending upon the use of the blocky building, Kutner says the open space between the cubes could be enclosed to house elevator shafts and heating, water, and ventilation pipes, as well as a lobby.

—*Robert Burg*



An angular floorplan (right) is just one characteristic of this blocky design. Three cubes, clustered together, form the Toronto building (far right).

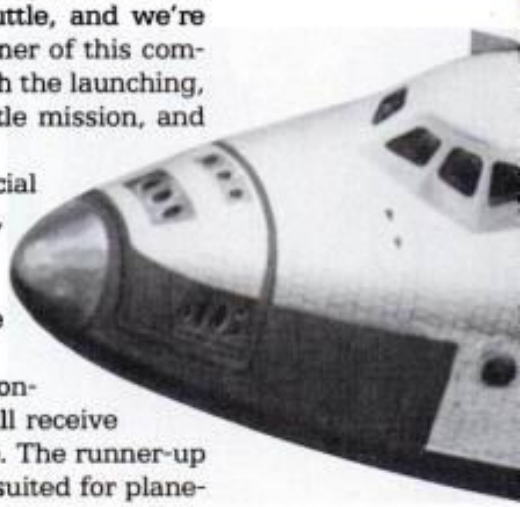
Материал, защищенный авторским правом

PUT YOUR OWN PROJECT ON THE

If PM picks your experiment to go on the Space Shuttle, you'll fly to Florida free to see it launched!

BY DENNIS ESKOW SCIENCE EDITOR

If there's any pioneering spirit in you, hang onto your seat—you're about to get invited aboard the Space Shuttle. Think of it as "T-minus three months and counting." PM has purchased space in the cargo bay of the Shuttle, and we're inviting you to think up an experiment to send into orbit. The winner of this competition and a friend or relative will be flown free to Florida to watch the launching, then on to Houston to join ground control in monitoring the Shuttle mission, and finally to California or Florida to watch the Shuttle touch down.



We're the first magazine in our field to join NASA's Getaway Special (GAS) program, but we probably won't be the last. At this writing, more than 400 universities, corporations, private individuals and one Japanese newspaper have purchased the right to fly an experiment. We have ticket No. 68, which means your experiment could be launched within a year after we start putting it together.

Your travels to the launch, mission control and landing will be sponsored by the Bushnell Div. of Bausch & Lomb. The winner also will receive Bushnell's Criterion 4000 telescope, an outstanding reflector scope. The runner-up will win a Celestron C-90 spotter scope, a compact telescope well suited for plane-

COMPETITION RULES

Phase 1

1. Entries should be typewritten or block-printed on a single sheet of white paper. Your name and full address should be centered at the top of the page.

2. Experiments should fit inside a 2.5-cu.-ft. canister and weigh less than 60 pounds.

3. Any experiment involving plant or animal life should explain how life would be sustained, since we're traveling in the airless cargo bay.

4. No project involving lithium batteries will be accepted. NASA won't allow them on the shuttle. Small, commercial-quality NiCd packs and off-the-shelf batteries for microprocessor systems are the best.

5. Materials should be able to withstand temperatures up to 200° F. and gravitational forces of 4 g— four times the gravity of earth. They also should be able to handle noise levels of 145 decibels. Vertical acceleration of 4 g, forward acceleration of 1.8 g and lateral acceleration of 1.2 g may occur at the same time with some Space Shuttle maneuvers.

6. Some structural plastics and composites may outgas and deteriorate in a vacuum. The idea you submit should take this into account.

7. On touchdown, cargo bay temperatures could rise to 180° F. Forced air circulated around the bay at about room temperature should keep it cool, but some provision should be made for sudden temperature variations.

8. Your experiment will be kept in storage a maximum three months before and a minimum three weeks after launch at room temperature and prevailing moisture conditions.

9. Experiments involving possible dangerous substances—such as explosives, or possibly dangerous configurations, such as gas containers—should pro-

VALUABLE PRIZES

Win PM's Space Shuttle competition and you'll get an expense-paid trip for two to Cape Canaveral for the launch. Then you'll fly to Mission Control in Houston and, finally, go on to either Florida or California for the landing. You'll also win a Bushnell Criterion 4000 telescope (far left). It's a twin to the Dynamax, which we praised last year (see Back-Yard Voyage To The Stars, page 86, June '82). Runner-up wins a Celestron C-90, also highly rated last June.

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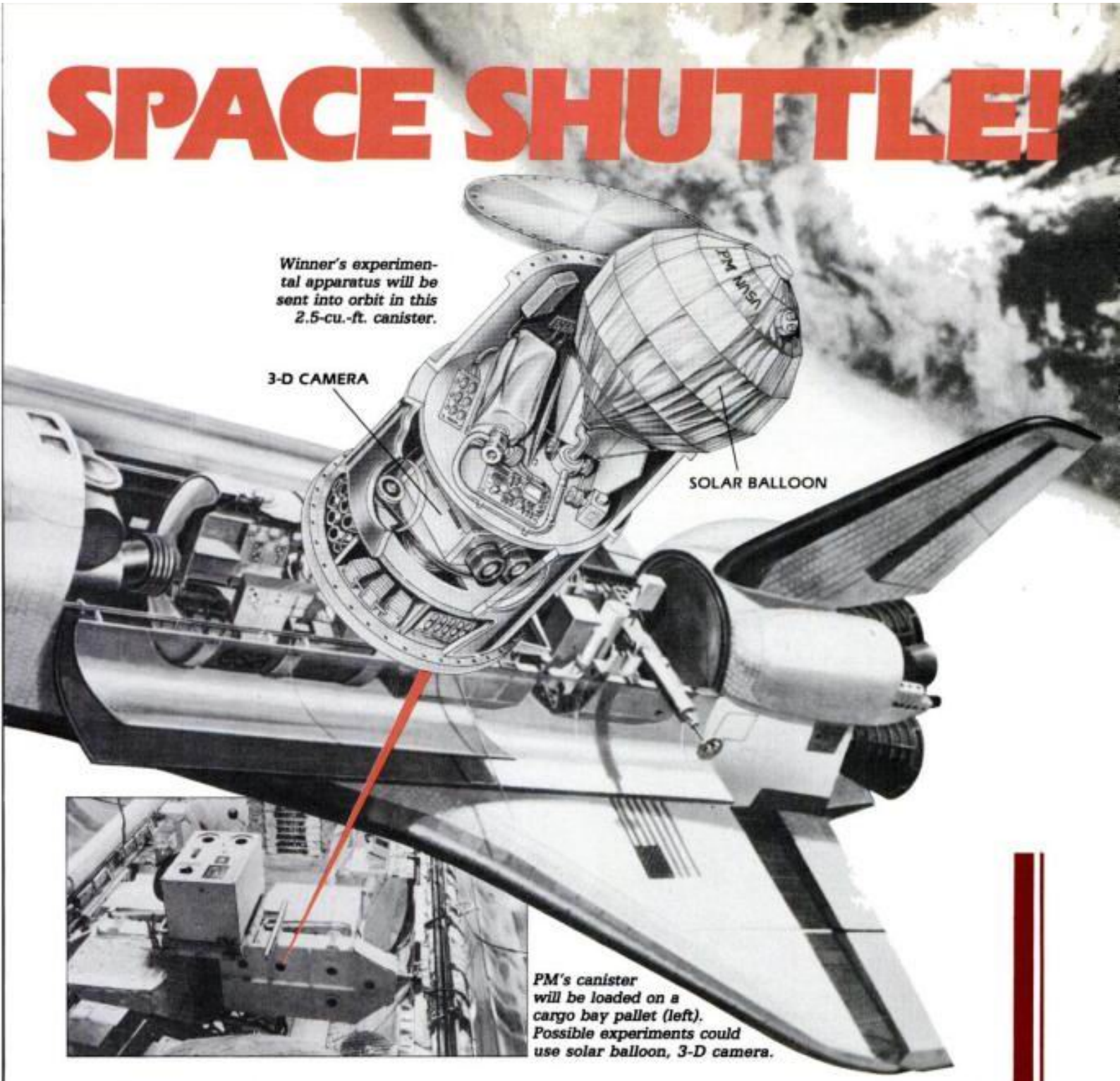
SPACE SHUTTLE!



Winner's experimental apparatus will be sent into orbit in this 2.5-cu.-ft. canister.

PM's canister will be loaded on a cargo bay pallet (left). Possible experiments could use solar balloon, 3-D camera.

vide for safety to the vessel and bay area. Most shuttle systems require a safety factor greater than one, meaning you must provide for basic safety with backups to reduce the chances for failure.

10. All proposals for multiple experiments should include proposals for monitoring the experiments. Telemetry, or any equipment that beams a radio signal to earth, is generally not permitted in the cargo bay area. Multiple experiments may be turned on and off by conditions in the bay area, such as sudden gravitational shifts or sudden changes in temperature.

Regardless of the number of experiments we carry, the astronauts will be permitted to throw our command switch only twice. That is why all experiments have to feed off the common switches.

11. All entries become the property of *Popular Mechanics,* which reserves the right to print all or part of the entry and the author's name. Devices designed for this mission may be patented by PM or one of the participating institutions with PM's permission.

12. All entries must be postmarked by midnight, July 30, 1983. Only winners will be notified. No entries will be returned. Sorry, but the volume of mail may prohibit us from answering inquiries.

Phase 2

The top 25 entries from Phase 1 will be entered into the second phase of the contest automatically. Finalists will be notified in late August and receive more detailed information on the experimental conditions. Each finalist must then write an expanded version of his proposal—to a maximum of 10 pages, including illustrations. The final proposals must be submitted to PM postmarked no later than midnight, Dec. 1, 1983.

If there's room in our canister, PM may send the second-prize entry aloft with the winner. In addition, the experimental apparatus may differ from the submitted proposal. PM reserves the right to construct the final version under its direct supervision.

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TECHNOLOGY

THE RESCUE OF BOX TOP 22

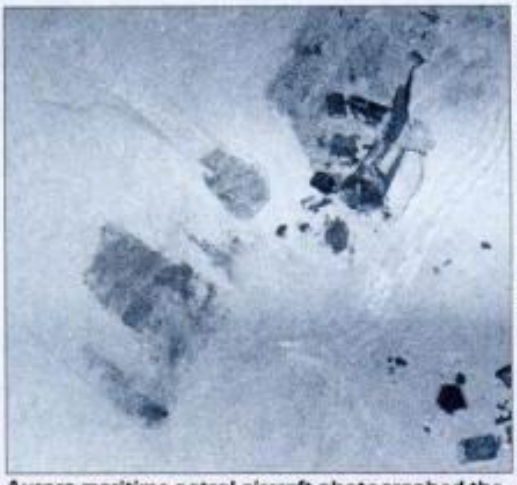
The crash of a C-130 pits a massive rescue force against the deadly Arctic night.

BY DAVID HUGHES
PM Illustration by Paul Dimare

● Maj. Marvin Macauley turned his C-130 rescue aircraft back toward the darkened crash site and lined up for another pass, flying as low as he dared. In the cargo bay, his brother, Warrant Officer Arnie Macauley, and five other Search and Rescue Technicians (SARTECHs) were suiting up to dive into the high arctic blizzard raging below.

Safety margins were razor thin, but both Macauleys knew the situation on the ground was desperate. An unknown number of survivors lay in the wreckage of another C-130 below, whipped by 30- to 40-knot winds and temperatures that would freeze exposed flesh in 15 seconds.

They'd been down there for 30 hours. Their aircraft, part of a resupply effort called Operation Box Top, had crashed 11 miles short of the lone gravel airstrip at Alert, a top-secret Canadian Forces base near the North Pole. Callsign Box Top 22 broke up on impact, and although all 18 aboard survived the crash, flames from spilled diesel fuel engulfed their survival gear. Within hours, a howling blizzard closed in. Cloaked in the Arctic's near-constant darkness, they were almost unreachable by ground or by air.



Aurora maritime patrol aircraft photographed the wreckage with an 11-million-candlepower flash.

CANADIAN FORCES PHOTO

SOS by satellite

Word of the crash got out almost immediately. A U.S. SARSAT satellite passing overhead picked up the plane's emergency locator beacon and relayed the signal to a ground station. Within an hour, Canadian Forces bases in Greenwood, Nova Scotia, and Edmonton, Alberta, were alerted. Leaders began rounding up every SARTECH available, while C-130s were loaded up with extra survival equipment.

Edmonton's C-130 was the first to launch, carrying 12 SARTECHs and an extra flight crew for the 2100-mile trip north. The Macauleys' C-130 took off from Greenwood shortly afterward with a total of 14 SARTECHs. Two more C-130s followed from Edmonton—one with an airdroppable survival kit for 40 people and another with a partially dismantled Twin Huey helicopter. Gander and Trenton each sent heavy twin-rotor Labrador helicopters lumber-

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Signals bounced off SARSAT sent aircraft scrambling from lower Canada, Alaska, Iceland and Newfoundland. Key players included three C-130s from Edmonton, carrying SARTECHs, supplies and a Twin Huey helo. The first SARTECHs to reach the scene came from Greenwood. Labrador helos couldn't make the long haul from Trenton and Gander, but a mammoth USAF C-5 transport brought two Alaska Air National Guard Pave Hawks within striking distance. Canadair Challenger medevaced the injured back to Ottawa.

ing northward, with 4-engine Aurora maritime surveillance planes guiding them from above.

As the air fleet worked its way north, Maj. Donald A. Hanson, who had directed Operation Box Top from Alert, organized an immediate rescue attempt. Volunteers were mustered to drive the base's four Go-Tracks—box-like, 13-ton, treaded utility vehicles—to the crash site.

They made slow progress, but 5 hours after the crash, the Go-Tracks were within about 2 miles of the wreckage. They got close enough to see flares set off by the survivors, but were blocked by the Sheridan River. They had to turn back, and as they did so, the storm began closing in.

Meanwhile, the first C-130 from Edmonton was approaching the crash site. Warrant Officer Fred J. Ritchie had some of his SARTECHs suit up for a possible jump. They tossed a 3-ft. magnesium parachute flare out the back of the plane to see what was below, but its 2-million-candlepower flame was quickly lost among the clouds. Unable to jump, they went on to Alert to change crews and refuel.

Grouping and regrouping

Ritchie went inside to talk to Hanson about the plan of attack. He proposed a second overland attempt using two of the Go-Tracks. He would split his SARTECH team and take six men with him while six others stayed with the C-130. Hanson agreed, and four

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SPACE TECH

GONE FISSION

NASA weighs nuclear options for lighting up moon bases

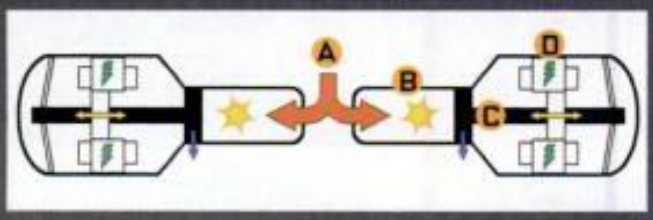
WHEN LUNAR ASTRONAUTS flick on their televisions after a long day of prospecting, they'll have a trashcan-size nuclear reactor to thank for their nightly dose of prime time. NASA, looking past the already daunting task of simply getting humans to the moon by 2020, recently started considering proposals for ways to power lunar habitats. Batteries and fuel cells provide only short-term solutions. Solar power would be limited where a single night lasts as long as 354 hours. So space-agency officials have started making plans to go nuclear.

The outline for the Fission Surface Power (FSP) plan is fairly straightforward: An underground, uranium-powered nuclear reactor produces heat and drives a power converter to generate electricity. The nuke plant would churn out 40 kilowatts of electricity, enough power to provide life support to four astronauts with plenty left over to mine oxygen from lunar soil and run moon buggies.

NASA is mulling two power-converter designs. Ohio-based SunPower has offered up a pressurized-gas-and-piston Stirling engine, which is going head-to-head with a Brayton-cycle engine that heats compressed gas to spin a turbine by the Colorado company Barber-Nichols [see illustrations below]. The Stirling engine is slightly more efficient at generating electricity, but the Brayton's proven design stands less risk of breaking down. Within the next year, the space agency will select a power converter and, for the next five years, test the unit using an electrical-resistance heater in place of the nuclear reactor.

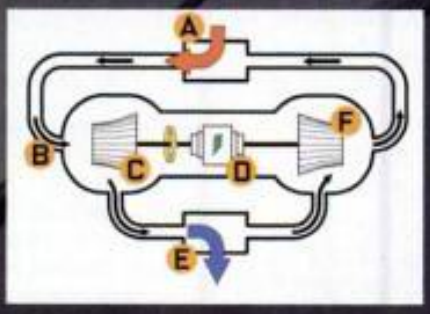
Whichever power converter emerges victorious, FSP is perfect for the moon, says Jim Werner, the reactor project manager at the U.S. Department of Energy's Idaho National Engineering Laboratory. With most parts moving slowly and infrequently, it should run maintenance-free for eight years, he says. "You can put it in place, turn it on, and forget about it for the duration of the mission."—DAWN STOVER

TWO OPTIONS FOR TURNING NUCLEAR HEAT INTO ELECTRICITY



STIRLING CONVERTOR: MORE EFFICIENT
Reactor heat [A] alternately expands and compresses helium [B] in a sealed chamber. This movement drives two opposing pistons [C] back and forth, and an alternator [D] turns that energy into electricity.

BRAYTON ENGINE: MORE RELIABLE



Reactor heat [A] expands compressed gas [B] and blasts it through a turbine [C], which turns an alternator [D] to generate electricity. After spinning the turbine, the gas flows into a recuperator [E] that sends waste heat to the radiators and the gas through a compressor [F] to pressurize it for the next cycle.

RADIATORS
Water circulates excess heat through the radiators. The greater the temperature difference between the radiator and the reactor, the more efficently the converters run, so the system will work best at night, when outside temperatures are coolest.

REACTOR
The trashcan-size nuclear reactor, under development by the U.S. Department of Energy, is fueled by uranium-oxide pellets encased in rods. A molten mixture of sodium and potassium circulates through the reactor core and carries heat to the power converter. Installing the reactor six to eight feet belowground would reduce the amount of heavy radiation shielding NASA would need to send to the moon and would allow the plant to be safely located within 330 feet of the habitat.

(CONTINUED FROM PAGE 19)

healthy coral-reef ecosystems should look like and, if well-preserved, could teach us how to better steward damaged reefs closer to civilization.

But how well this "underwater laboratory" is protected will be key to the initiative's success. Bush has the power to prohibit fishing, deep-sea mining and oil drilling in the area. Without such a ban, environmentalists say, the initiative would amount to a grand but meaningless gesture. For now, there's almost no fishing, mining or drilling

Eroding reefs and dwindling fish populations make conservation more urgent.

in the central Pacific—it's too remote to be economically viable, says Joshua Reichert, managing director of the Pew Environment Group, which has been discussing protections with the Bush administration since 2006. But fisheries could target the tuna that migrate through the region or hunt sharks for the lucrative Asian shark-fin trade.

Although public opinion on the few inhabited islands leans in favor of the plan, the Northern Marianas House of Representatives voted against monument designation, citing fear over future fishing restrictions. A similar proposal for islands off North Carolina and in the Gulf of Mexico was dropped last year after vigorous opposition from industrial fishing interests.

Somewhat ironically, Bush's best ally in this battle may be climate change. With warmer waters and spiking ocean acidity eroding coral reefs, and 90 percent of the world's predatory fish—such as tuna, sharks and swordfish—eradicated, conservation takes on a new urgency. "It is imperative," says Lance Morgan, vice president of the Marine Conservation Biology Institute, "to fully protect this monument."—SHARON GUYNUP

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ALTERNATIVE AVIATION

ALL ABOARD THE AEROTRAIN

A vertical-takeoff concept commercial plane could get you in the air faster

IN THIS AGE of eternal flight delays, traveling from New York to Miami in the scheduled three hours sounds like a fantasy. Yet within a decade, aircraft designer Abe Karem plans to fix that by bypassing congested runways in his tilt-rotor, vertical-takeoff commercial plane, the AeroTrain. Sitting on a helipad with its twin rotors tilted straight up, the craft can take off vertically and fly like a helicopter. Once the plane has reached a safe altitude of 50 feet, the pilot will tilt the rotors forward and fly the craft like an airplane.

But, you ask, didn't the military's tilt-rotor Osprey V-22 claim the lives of 30 people during test flights? Karem, who specializes in designing tilt-rotor aircraft, says he's learned from those early failures. The AeroTrain adopts the military's warning system for altitude-stealing turbulence conditions and replaces easily shredded hydraulic control lines with electric motors. And it will use computer software that prevents the pilot from flying into turbulence when landing. "It's a different animal than the V-22," says Daniel Schrage, director of the Army Center of Excellence for Rotocraft Technology at Georgia Tech.

Although the 120-passenger plane's top speed of 410 mph is 20 percent slower than a similar-size Boeing 737, Karem explains that time saved on the ground will make up for that lost in the air, especially on shorter flights. "Two hundred to 1,000 miles, that's our niche," he says. Karem aims to have the AeroTrain in production before 2018. Until then, if you're flying out of a busy airport, you might want to pack a sleeping bag.—MICHAEL BELFIORE

JOHN MCNEILL

step is to infuse the hearts with a mix of mature and progenitor cardiac cells, which can come from a patient's own body to ensure compatibility. Incredibly, for reasons the team still doesn't understand, the cells seem to know how to divide and proliferate into cardiac tissue inside the empty-shell hearts.

This year, Taylor has continued to forge ahead toward her goal of creating transplantable, made-to-order human organs. Soon after she published her rat-heart results, she started working on making recellularized pig hearts—closer in size and shape to the human equivalent—that could pump blood and generate electrical impulses. "Our hope is that someday we'll be able to take a cadaver or pig organ, decellularize it, and transplant your own cells into the matrix to make an organ that matches your body," Taylor says.

Before a reliable human donor heart can be grown from a matrix, however, scientists must coax it to do more than just beat. "A heart isn't just a muscle. It also needs arteries and other tissues," explains cardiologist Robert Bonow of Northwestern University. "Doris Taylor has replaced the motor inside the chassis, so to speak, but she's got to find a

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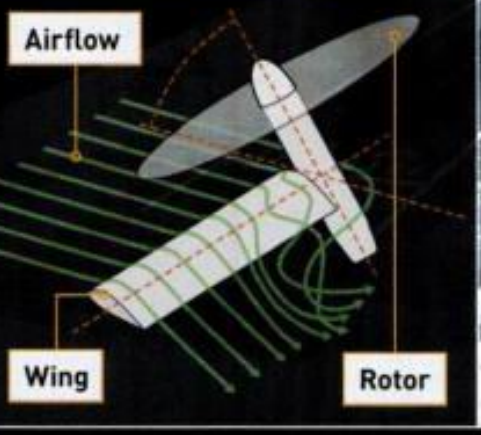
TILT ROTORS
The TR53 AeroTrain's twin rotors point upward for takeoffs, landings and hovering flight. Shortly after takeoff, the rotors tilt forward for horizontal flight at speeds of up to 410 mph at a cruising altitude of 30,000 feet.

ELECTRIC ACTUATORS
The AeroTrain moves its ailerons and rudder and tilts its rotors using electric motors instead of the typical high-pressure hydraulic lines, thus eliminating the risk of rupturing the lines when tilting the rotors.

TWO-SPEED TRANSMISSION
The AeroTrain's two-speed transmission downshifts from the fast rotation needed for vertical flight (just how fast is a proprietary secret) to a more fuel-efficient 40-percent-of-maximum speed for cruising flight.

ARE TILT-ROTOR AIRPLANES SAFE?

The key to successful—and safe—tilt-rotor flight is a smooth transition from horizontal to vertical flight when landing. If the pilot descends too quickly, the rotors can drop into their own spiraling wake [green], a dangerous condition known as a vortex ring state (VRS) in which the churning turbulence prevents the rotors from generating adequate lift. If even one rotor enters VRS, it can cause the plane to roll over. It was VRS that cost the Marines one V-22 Osprey and 19 troops during one test flight. The military has since developed early-warning software that tips off pilots when they're descending nearly too quickly and about to go into VRS. Better still, AeroTrain has developed software that locks flight controls before the plane enters VRS, and pilots are now trained on how to maneuver to pull out of a death dive.



"By eight days, we could see the whole heart beating," says Taylor. "The first time that happened, it was like, 'yes!'"

way to get the other parts in there too."

She's working on it. Taylor's team has washed away the cells inside a rat aorta, for example, which is about the same size as a human coronary artery, and successfully seeded it with rat endothelial cells. The blood vessels grown in the lab are strong enough to withstand 19 pounds of pressure per square inch, a high enough performance threshold to make them viable in transplant hearts.

Taylor is focused on starting human clinical trials in the near future; she envisions a transplantable organ becoming available in "years, not decades." But she's also looking at the incredible number of other possible uses for her cell-seeding procedure. "The coolest thing is, it's not just about hearts—we could do this with kidneys, lungs and livers as well."—ELIZABETH SVOBODA

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ENERGY

COAL'S SECOND INDUSTRIAL REVOLUTION

With the new FutureGen power plant, turning coal into electricity doesn't have to be a nightmare for the environment

COAL, THE 19th CENTURY'S fuel of choice, is still going strong in the 21st. The U.S. is by far the world's biggest source of the fossil fuel, mining 1.1 billion tons of it a year. Coal may be cheap—just $1.68 per million BTU, compared to $6.45 for natural gas—but it exacts a higher price in pollution, with some 1,650 times as much sulfur dioxide, four times as much nitrogen oxide, and twice as much carbon dioxide released per kilowatt-hour of electricity.

In an effort to save the environment from coal's noxious emissions, the U.S. Department of Energy and major power companies plan to build FutureGen, a coal-gasification plant that will liberate clean-burning hydrogen from coal while siphoning off the carbon dioxide for injection into underground saltwater deposits. The first full-size power plant of this type is slated to go online in 2012. Here's a look at how it will operate.—SEÁN CAPTAIN

HOW FUTUREGEN WORKS

STEP 1: GASIFY COAL

Coal, **water** and **oxygen** are rapidly heated under high pressure to produce a mixture of hydrogen (H_2) and carbon monoxide (CO) called **syngas**. The syngas enters a **cleaner**, where sulfur is filtered off for use in the chemical industry and at least 90 percent of the mercury is captured. Other metallic pollutants are converted to an inert solid called slag.

gasification a step further by burning only the hydrogen from syngas. The carbon monoxide is combined with steam to produce additional hydrogen, along with CO_2 that will be pumped 2,700 to 16,000 feet underground into deep saline reservoirs. The U.S. alone has the geological capacity to store up to 2.2 trillion tons of CO_2, roughly 1,000 years' worth of U.S. power-plant emissions, estimates Julio Friedmann, who directs research on CO_2 sequestration at Lawrence Livermore National Laboratory.

In July, FutureGen will complete environmental-impact assessments on

Sequestering carbon is less a long-term solution and more a good stopgap.

four possible sites, two each in Illinois and Texas. It will pick a final location before the end of the year and start construction in 2009. Thanks to international efforts to rein in heat-trapping gases, and anticipated federal carbon regulations, FutureGen has attracted heavy hitters from the energy industry—such as AEP and Peabody Energy, America's biggest coal supplier—that want to get a jump on carbon-squelching technologies. Among the alliance's international members is the China Huaneng Group, the largest coal-based power generator in China.

But for FutureGen to make a dent in CO_2 emissions, it must become the blueprint for all the coal-fired power plants to follow. And the federal government must set nationwide CO_2-emission limits for power plants similar to those that are in place in other parts of the world, including Canada and Europe, as well as those under consideration in California and several other states.

Experts agree that the whole notion of trapping carbon is less a long-term solution and more a good stopgap. "Carbon sequestration you can do for 50 or 100 years," Friedmann says. "You do it until you have other options besides burning coal—which we kind of don't right now."—SEÁN CAPTAIN

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ARCHITECTURE

THE LIVING MUSEUM

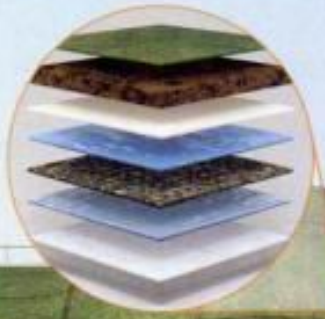
For a newly minted museum in San Francisco, the green architecture is the main exhibit

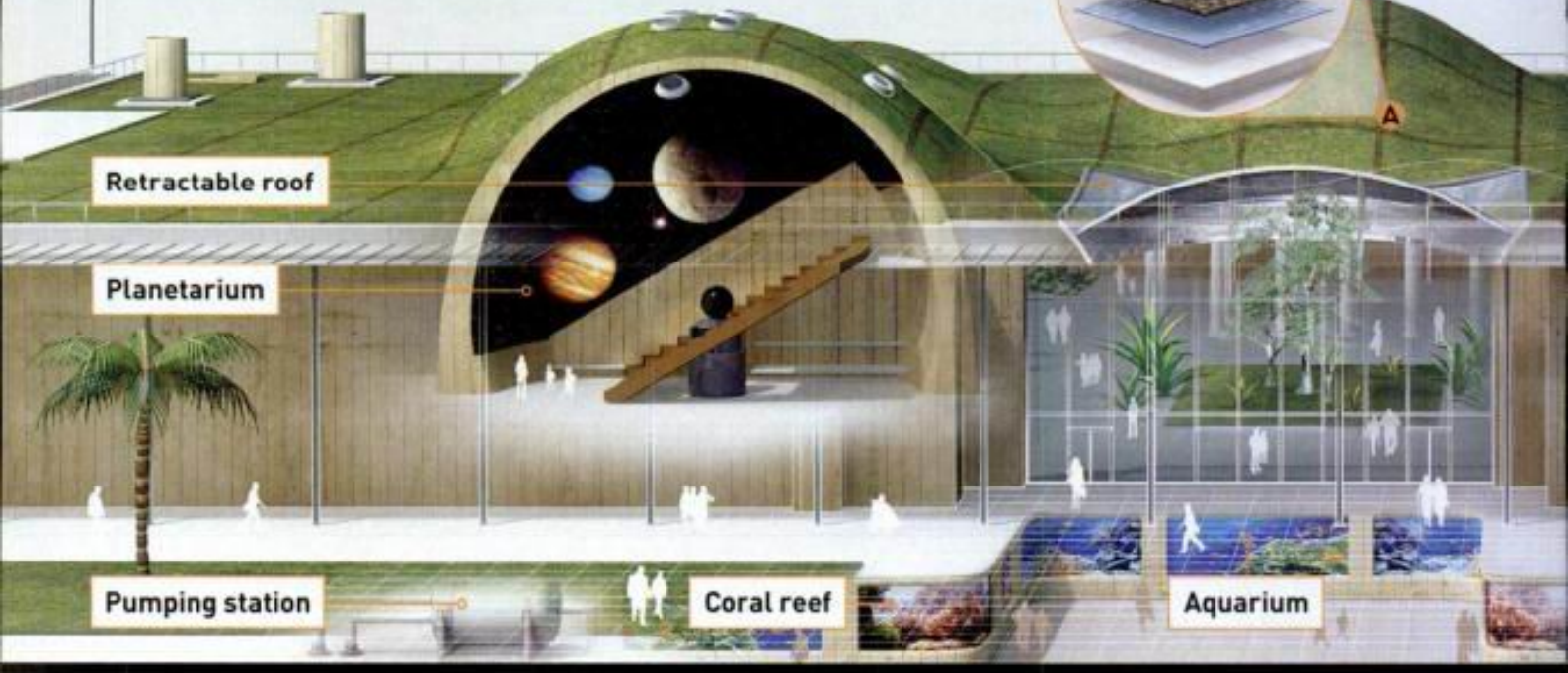
FROM A BIRD'S-EYE VIEW, the domes of the California Academy of Sciences, set to open in the fall, bulge out of the ground like giant scoops of green ice cream. These undulating hills built into the museum's 2.5-acre, flora-covered roof integrate the building into the green space of surrounding Golden Gate Park. They also conserve energy, since the roof insulates and ventilates the 400,000-square-foot museum below.

Designed by renowned Italian architect Renzo Piano, whose works include the landmark modern-art museum Centre Pompidou in Paris, the $484-million structure will most likely be the largest public building ever to qualify for the U.S. Green Building Council's "platinum" LEED (Leadership in Energy and Environmental Design) rating. The designation, so far held by just 70 buildings worldwide, is the highest honor in green construction.

Beneath the roof, museumgoers will find a natural-history museum, a planetarium, a rainforest with free-flying birds, a coral reef inhabited by 4,000 fish, and an aquarium filled with saltwater pumped in from the Pacific Ocean. The most influential display, though, may well be the marriage of the museum's physical design with its educational mission. "It's not about dusty stuffed animals," says executive director Greg Farrington. "It's about human survival and living in harmony on planet Earth."—KALEE THOMPSON

ROOTED IN SUSTAINABILITY
The living rooftop is tiled with 50,000 biodegradable trays made of coconut husks. Each tray is specially layered to keep plants from slipping down the roof's steep slopes.





ILLUSTRATIONS: GRAHAM MURDOCH; PHOTOGRAPHS, FROM LEFT: CHARMAGNE LEUNG AND STEPHANIE STONE/CALIFORNIA ACADEMY OF SCIENCES

short period of time. Roger Kay, the president of computer-industry analysis and consulting firm Endpoint Technologies Associates, which has followed OLPC since its conception, says the nonprofit is "doing OK—not brilliantly, but all right." Although the XO works well for a low-cost device, he says, the execution of the project—everything from failing to secure buyers in large markets such as China and India, to relying on pro-bono distributors, to its public breakup with Intel—is indicative of OLPC's lack of business experience.

The question is how quickly the organization can learn from its mistakes. Bender remains unfazed by the program's rocky start—"We're looking at getting millions [of laptops] out in 2008," he says—but in the coming year, the nonprofit will need to recruit a new CTO and fill Intel's vacancy by enlisting a partner wealthy enough to replace the chip maker's millions of dollars in funding. Resolving the Nigerian dispute is also key, because OLPC is prohibited from doing business in that populous market (an

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INSIDE THE GREENEST MUSEUM

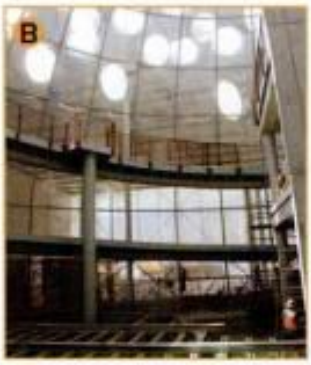
THE LIVING ROOF
Planted with nine local species, the 2.5-acre roof **[A]** is the largest swath of native vegetation in San Francisco. It absorbs 98 percent of rainwater, so it doesn't need irrigation.

VENTILATION
Computer modeling of local wind patterns helped architects place the roof's seven mounds to maximize air flow. The valleys correspond with open areas in the exhibition space below. Cool air blowing through the mounds draws warm interior air up through vents in the ceiling, providing constant circulation that reduces the need for air conditioning.

RETRACTABLE ROOF
Between the planetarium and the rainforest is the museum's central plaza, which opens via a retractable Mylar rain screen.

LIGHTING
Natural light reaches 90 percent of the building's exhibition spaces, minimizing the use of electricity. In addition, the building's walls and skylights **[B]** are made of high-performance glass that reflects most heat, while rooftop solar panels supply up to 10 percent of the museum's electricity needs.

MATERIALS
All of the building's structural steel comes from recycled sources. The concrete contains 30 percent fly ash (a by-product of coal plants), and the structure is insulated with recycled blue jeans.



WATER USE
A pumping station at nearby Ocean Beach sucks water two and a half miles from the Pacific through a buried pipe to a holding tank in the museum's basement, where it is treated, heated, and distributed to the aquarium and coral reef.

PARK-N-PLUG
The museum offers a recharging station for electric and plug-in vehicles.

PopSci ON THE WEB Take an animated tour of the museum at *popsci.com/green*.

The question is what One Laptop Per Child can learn from its mistakes.

estimated 57 million children) until the matter is settled. Additionally, OLPC plans to streamline production, roll out machines that will work in other languages, and continue developing the next version of the XO, which Bender expects will come closer to the $100 mark when it is released in a few years.

Meanwhile, despite OLPC's turmoil, families are putting the XO to good use. Last March, 20 students in Ban Samkha, a remote, rice-growing village in Thailand, got their hands on the machines—a first for some. They quickly began to use Google, connect with new friends around the world, and monitor local weather to help alert the landslide-prone village when it's at risk. The Ban Samkha experience serves as a vivid reminder that the OLPC project is worth rooting for.—AMY FELDMAN

Материал, защищенный авторским правом

THE FLYING LASER GUN

Boeing's new laser cannon [illegible] and 10,000 feet up—and it's ready

BY ERIC ADAMS

CREATING A LASER that can melt a soda can in a lab is a finicky enough task. Later this year, scientists will put a 40,000-pound chemical laser in the belly of a gunship flying at 300 mph and take aim at targets as far away as five miles. And we're not talking aluminum cans. Boeing's new Advanced Tactical Laser will cook trucks, tanks, radio stations—the kinds of things hit with missiles and rockets today. Whereas conventional projectiles can lose sight of their target and be shot down or deflected, the ATL moves at the speed of light and can strike several targets in rapid succession.

Last December, Boeing, under contract from the Department of Defense, installed a $200-million prototype of the laser into a C-130 at Kirtland Air Force Base in New Mexico in preparation for test flights this year. From there it will go to the Air Force for more testing, and it could be in battle within five years.

Precise control over the beam's aim allows it to hit a moving target a few inches wide and confine the damage to that space. The Pentagon hopes such precision will translate into less collateral damage than even today's most accurate missiles. Future versions using different types of lasers could be mounted on smaller vehicles, such as fighter jets, helicopters and trucks.

BEAM EXPANDER widens laser to 20 inches across

TURRET aims beam

BEAM CONTROL stabilizes laser beam

OPTICAL BENCH refines beam with mirrors

LASER BEAM travels in pipe above crew

OPTICAL RESONATOR creates the light pulse

BOB SAULS

SIZE: 2,600 CU. FT. ★ WEIGHT: 40,000 LBS. ★ COST: $200 MILLION ★ TIME IN DEVELOPMENT: 5 YRS.

Материал, защищенный авторским правом

HOW TO MELT A TANK IN THREE SECONDS OR LESS

1. FIND YOUR TARGET

When the C-130 flies within targeting range (up to five miles away), the gunner aims using a rotating video camera mounted beneath the fuselage. The computer locks onto the object to continually track it. A second crew member precisely adjusts the laser beam's strength—higher power to disable vehicles, lower power to knock out, say, a small power generator. The gunner hits "fire," and the computer takes over from there.

2. HEAT UP THE LASER

In a fraction of a second, chlorine gas mixes with hydrogen peroxide. The resulting chemical reaction creates highly energetic oxygen molecules. **Pressurized nitrogen** pushes the oxygen through a fine mist of iodine, transferring the oxygen's energy to iodine molecules, which shed it in the form of intense light.

3. AMPLIFY THE BEAM

The **optical resonator** bounces this light between mirrors, forcing more iodine molecules to cough up their photons, further increasing the **laser beam**'s intensity. From there, the light travels through a sealed pipe above the weapon's crew station and into a chamber called the **optical bench**. There, sensors determine the beam's quality, while mechanically controlled mirrors compensate for movement of the airplane, vibration and atmospheric conditions. Precise airflow regulates the chamber's temperature and humidity, which helps keep the beam strong.

4. STAND CLEAR

A kind of reverse telescope called the **beam expander** inside a retractable, swiveling pod called the **turret** widens the beam to 20 inches and aims it. The laser's computer determines the distance to the target and adjusts the beam so it condenses into a focused point at just the right spot. Tracking computers help make microscopic adjustments to compensate for both the airplane's and the target's movement. A burst of a few seconds' duration will burn a several-inch-wide hole in whatever it hits.

SEALED EXHAUST holds spent chemicals

PRESSURIZED NITROGEN forces oxygen and iodine together to create the laser

FAQ

HOW HOT IS THE BEAM? The laser itself isn't hot, but it can heat its target to thousands of degrees.

DOES THE LASER SEAR EVERYTHING IN ITS PATH? Yes. If a bird flew into the firing laser's line of sight—well, no more bird. Fortunately, the weapon will fire for only a few seconds at a time, minimizing the risk.

DOES IT MELT ITS TARGET OR JUST SET IT AFLAME? That depends on what it hits. It will melt metal, but if the target is combustible, it will burn.

★ BEAM SIZE: 20 IN. ★ RANGE: 5 MILES ★ TEST FLIGHT: THIS YEAR ★ INFO: *BOEING.COM*

Материал, защищенный авторским правом

Over the years, however, as he continued his NASA work in hydrogen systems, the references began to accumulate in his mind. "What I was starting to notice is that the authors were inconsistent," he says. Hydrogen detractors said the gas was so flammable it killed everyone on the *Hindenburg*, which wasn't true—about one-third of those aboard had died. On the other hand, hydrogen promoters pooh-poohed safety concerns and claimed that those who perished did so only because they jumped from the burning airship, which also wasn't true. Says Bain: "I thought, wait a minute! Where are they getting their information?" He had also seen the famous photos of the *Hindenburg*'s bright, blistering hot fire and knew that hydrogen doesn't burn in that way. A hydrogen fire radiates little heat and is barely visible to the unaided eye.

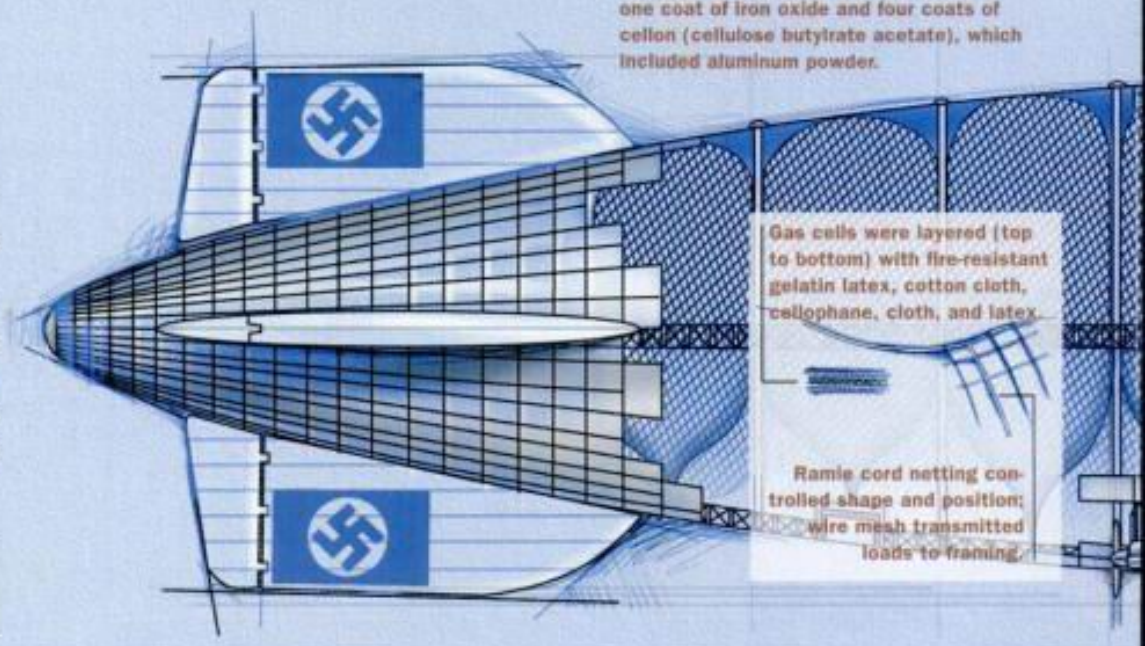
By 1990, Bain pulled a one-year assignment in Washington, D.C., at NASA headquarters, then across the street from the National Air & Space Museum. "I like airplanes, so I went over there. Lo and behold, there's this 25-foot-long model of the *Hindenburg* used in the 1975 movie with George C. Scott," he recalls. "I'm looking at that model and a plaque on the wall. The plaque says something about how the hydrogen exploded." As a hydrogen expert, he knew that the pure gas doesn't just explode. That was enough: He made an appointment with the archivists upstairs, donned a pair of protective gloves, and lost himself in decades-old original documents in the museum's *Hindenburg* files for the rest of the day.

His research soon became something of a part-time obsession. Over the next few years, Bain would steal

A Look Inside

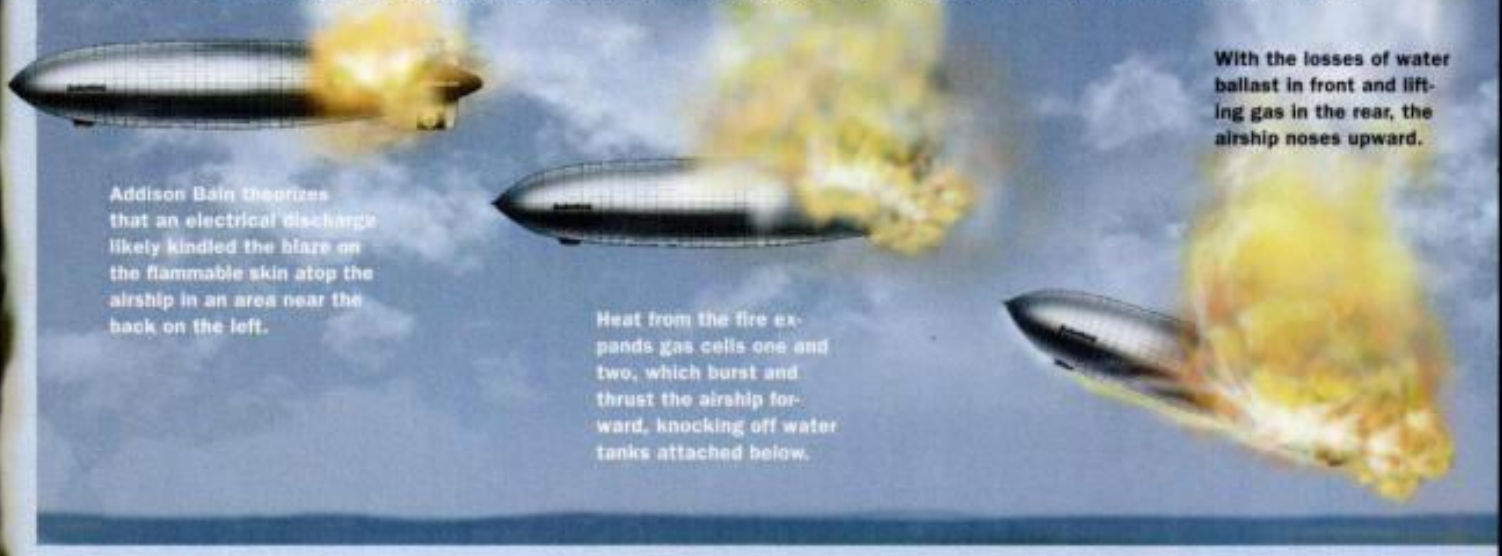
THE *HINDENBURG* used 16 dual cells to contain the lifting gases. Helium encased the hydrogen cells inside. "The idea was to retain expensive helium," says Addison Bain, "and the hydrogen, being relatively cheap, would help maintain trim by venting up the gas shafts." However, says Bain, it was the skin, not the hydrogen, that proved the great ship's undoing.

INFOGRAPHICS BY DANIELS & DANIELS



How the Airship Went Down

AFTER UNEVENTFUL Atlantic crossings and thousands of miles traveled, the *Hindenburg* went down in less than a minute.



Update: How well the new Zeppelin flew in tests www.popsci.com

away to the archive and travel to others in College Park and Suitland, Maryland, poring through thousands of pages and copying documents in search of answers. He even traveled to the Fire Sciences Lab in Missoula, Montana. He speculated that, perhaps, some of the airship's materials had played a role in the ignition. Maddeningly, however, he couldn't find the exact formulations used. "I had the idea of the problem, but needed enough evidence to back my story up," he says.

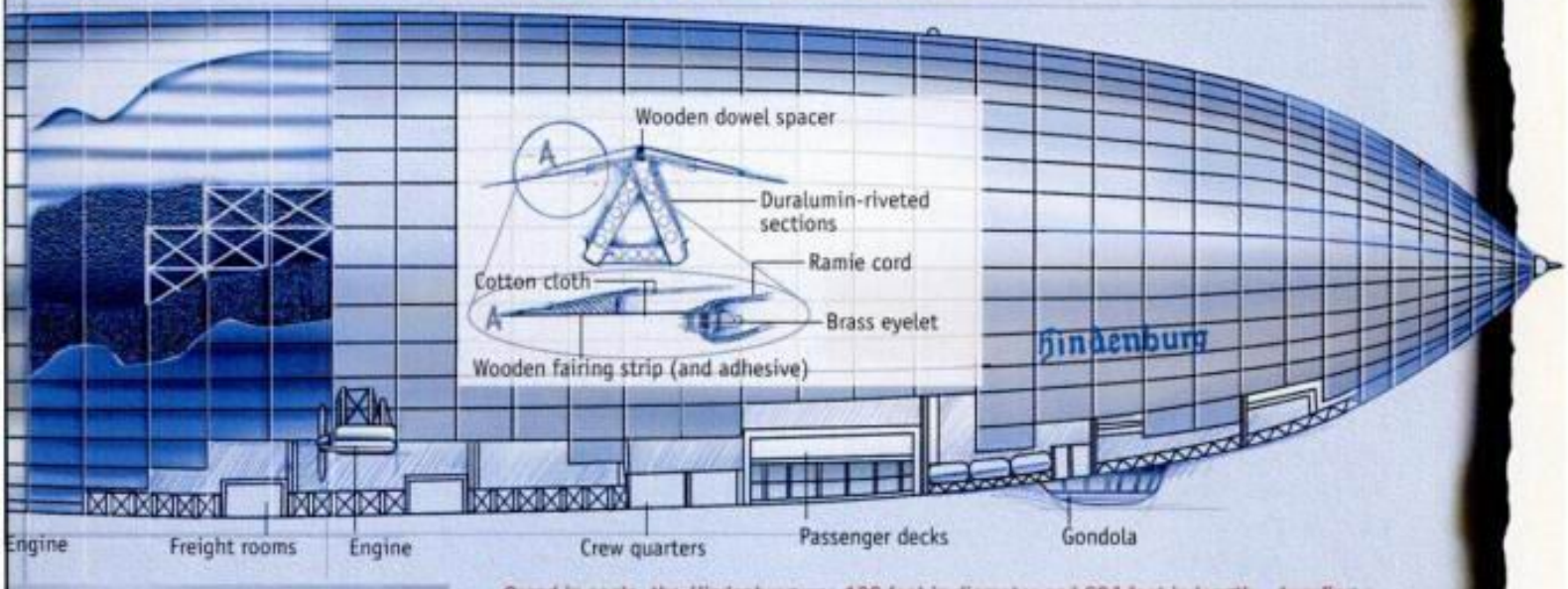
That was as far as he got until 1994, when he ran into Richard van Treuren, a space shuttle technician, at a conference on hydrogen. Van Treuren, a self-avowed "helium head" and member of the airship aficionados called the Lighter-Than-Air Society in Akron, Ohio, was seeking Bain to talk about hydrogen. Van Treuren had a book about airships. Bain spotted the book in the crook of van Treuren's arm and bought it from him on the spot.

The rain still spatters the wet ground in starts and stops. The air is highly charged from the thunderstorms, investigators would rule later. Six and three-quarter acres of Hindenburg *fabric is kiting in the breeze. A witness later would recall a bluish electrical phenomenon that dances over the aft starboard side of the* Hindenburg *for more than a minute.*

Through van Treuren, Bain learned that pieces of the *Hindenburg*'s skin still existed. Bain traveled around the country to procure them, spending hundreds of dollars buying original materials, books, and papers from collectors. "What I was trying to find out is, what did they use specifically in the coating?" he says.

Hepburn Walker, who had been stationed at Lakehurst

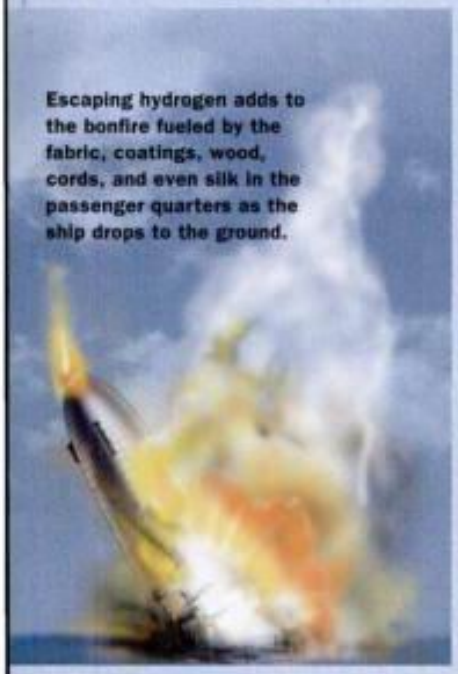
At the *Hindenburg*'s apex were wooden dowel spacers and fairing strips and duralumin-riveted sections coated with alkyd/acrylic pthalocynanine dye, which added fuel to the fire.



Grand in scale, the *Hindenburg* was 130 feet in diameter and 804 feet in length—dwarfing a modern 747 and the latest Zeppelin, the NT. (See the related story, "A Zeppelin Flies Again.")

Boeing 747 Zeppelin NT Hindenburg

Escaping hydrogen adds to the bonfire fueled by the fabric, coatings, wood, cords, and even silk in the passenger quarters as the ship drops to the ground.



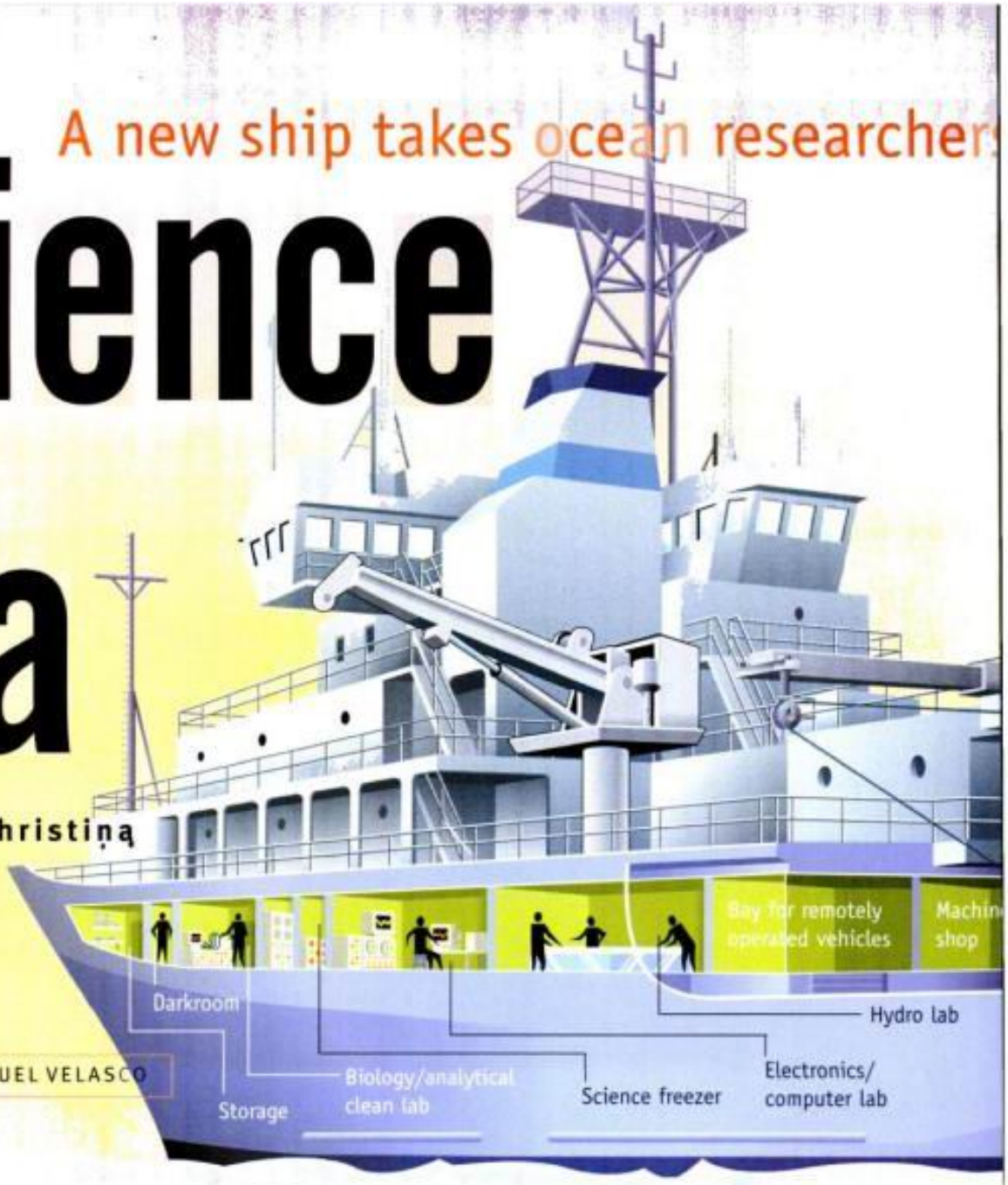
Addison Bain colorized this shot to match eyewitness testimony. Below right, in contrast, the three main engines of the space shuttle (center) show a typical, barely visible hydrogen-oxygen fire. Its two solid rocket boosters —which contain aluminum powder and red iron oxide, both used on the *Hindenburg*'s skin—burn bright.

Timeline: Follow the development of the first airships www.popsci.com

A new ship takes ocean researchers

Science at Sea

By Mariette DiChristina



INFOGRAPHIC BY SAMUEL VELASCO

OCEAN STUDIES THAT once took years to complete will now take mere days, thanks to a new research vessel named *Atlantis*. The 274-foot ship is the first to support both manned submersibles, such as the renowned *Alvin*, and unmanned remotely operated vehicles.

"The ship brings a lot of technology together that used to be separate," says Jim Luyten, director of research at the Massachusetts-based Woods Hole Oceanographic Institution, which operates *Atlantis*. Instead of surveying a site with one research tool and returning months later with another, scientists on *Atlantis* can conduct many kinds of research during a single visit.

For example, "you could tow cameras, then use a remotely operated vehicle for the initial survey, and manned vehicles to take bigger samples," says Patrick Hickey, the *Alvin* expedition leader. All these tools will be onboard for the next expedition, a 30- to 40-day voyage this summer to study the odd creatures living around hydrothermal vents along the seafloor's Mid-Atlantic Ridge. The ability to accomplish more on one trip will also save money: Ships like the $551 million *Atlantis* have daily operating costs between $25,000 and $35,000.

Atlantis is the newest of three sister ships built for academic institutions under Navy auspices; the Scripps Institute of Oceanography and the University of Washington operate the other two. (The Navy, which owns the ships and could call them into service during a defense emergency, benefits from seafloor mapping and other research performed by the vessels.)

Atlantis can travel for 60 days—approximately halfway around the world—without stopping for fuel. Its predecessor could run for only 45 days. Because *Atlantis* can cruise for greater distances, it will bring tools like *Alvin* to new marine vistas, such as the Indian Ocean and areas north of the Arctic Circle.

While they're visiting such places, marine researchers can take advantage of the latest gadgets aboard the ship. For instance, with dynamic positioning, a system that

everywhere they want to go.

THE LATEST IN a series of Woods Hole ships bearing the name *Atlantis*, the new vessel offers four times the lab space of its predecessor.

ABE (Autonomous Benthic Explorer)

Alvin manned submersible

Alvin hangar

ATLANTIS
WOODS HOLE

links the ship's GPS-based navigation and its steering, the pilot uses a joystick and an onscreen map to maintain a precise location over the ocean floor during studies. Onboard sonar can map a 3-kilometer-wide swath of the bottom as the ship cruises along: Sound pulses bounced off the seafloor are received by an array of some 80 transducers on the hull. An acoustic Doppler radar measures the horizontal and vertical speed of ocean currents. After receiving data from the ship's instruments, scientists in the floating lab can begin to evaluate the information using onboard computers linked by six miles of cable.

Now that the ship has been delivered to Woods Hole, researchers are anxious to set sail. After all, says Hickey, "We have the newest and best equipment around."

ATLANTIS SUPPORTS robotic vehicles such as ABE, the Autonomous Benthic Explorer; the remotely operated vehicle *Jason*; and the manned submersible *Alvin*.

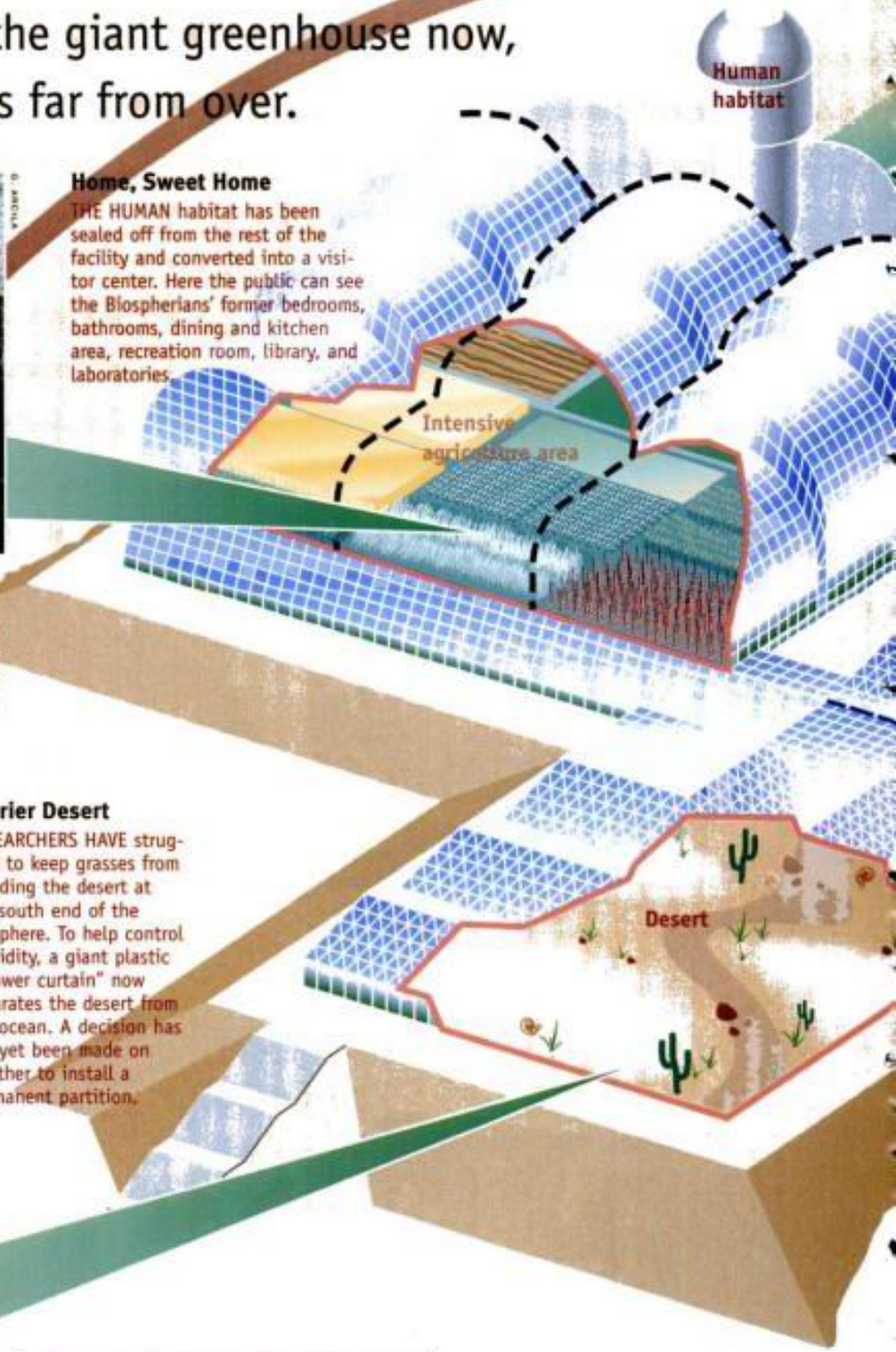
Jason remotely operated vehicle

Материал, защищенный авторским правом

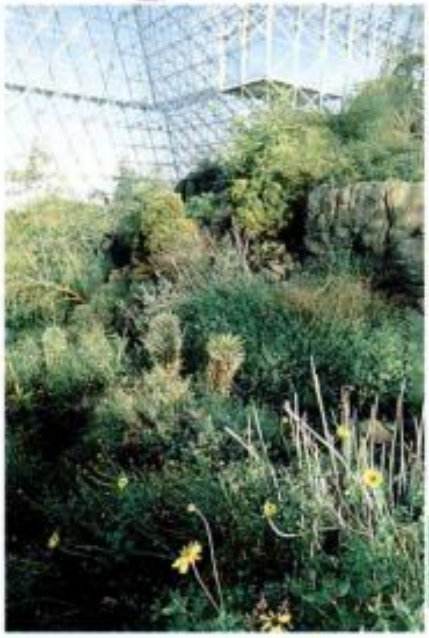
Second Chance for Biosphere

Nobody lives inside the giant greenhouse now, but the experiment is far from over.

Home, Sweet Home
THE HUMAN habitat has been sealed off from the rest of the facility and converted into a visitor center. Here the public can see the Biospherians' former bedrooms, bathrooms, dining and kitchen area, recreation room, library, and laboratories.



Biosphere's Backyard
BIOSPHERIANS GREW their food in the intensive agriculture area. It will now be partitioned into three identical sections for controlled scientific experiments. For example, the effects of different carbon dioxide levels on plant growth can be compared.



A Drier Desert
RESEARCHERS HAVE struggled to keep grasses from invading the desert at the south end of the Biosphere. To help control humidity, a giant plastic "shower curtain" now separates the desert from the ocean. A decision has not yet been made on whether to install a permanent partition.

INFOGRAPHIC BY GREG MAXSON

Материал, защищенный авторским правом

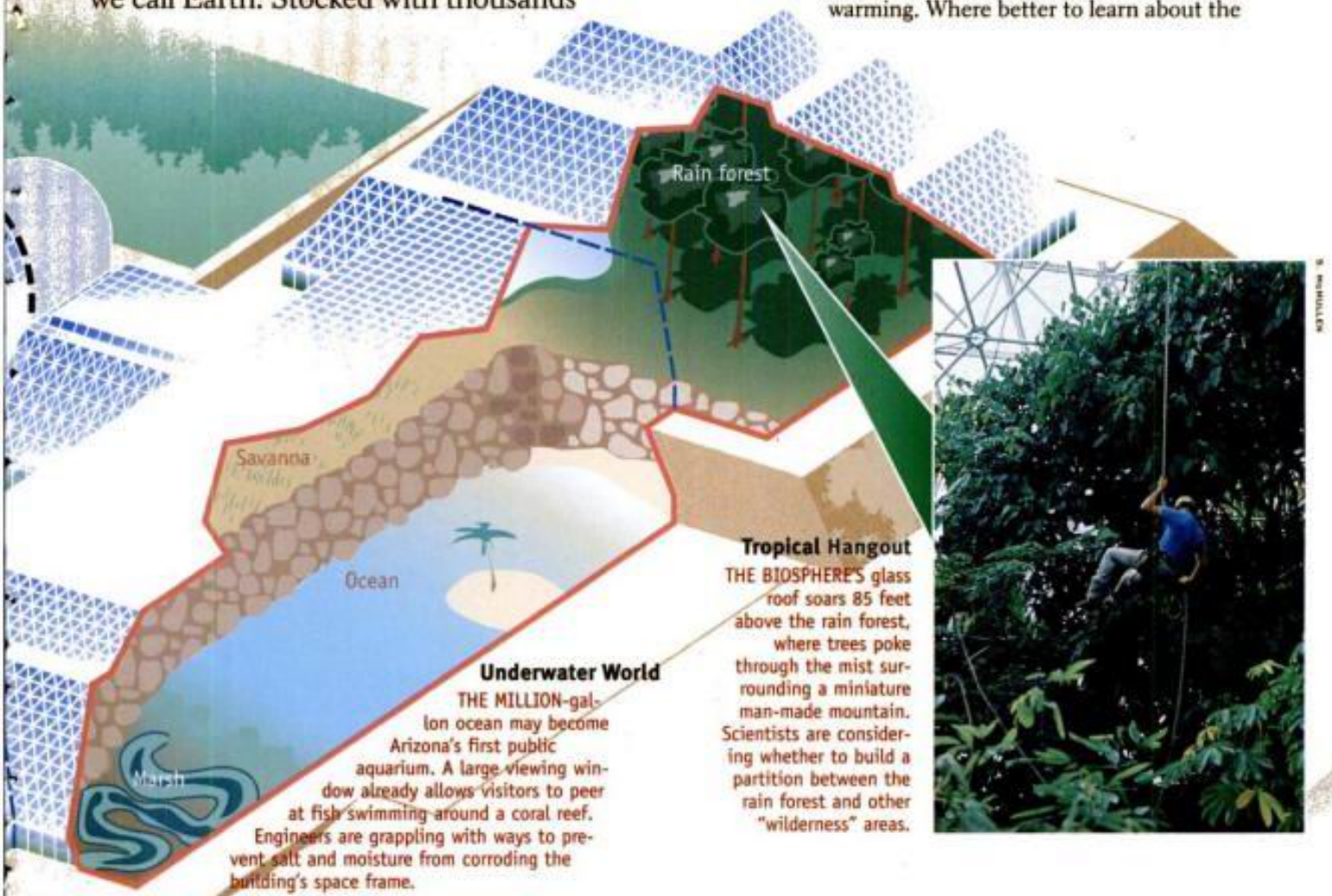
AFTER THE HOLOCAUST, cockroaches and ants inherit the world. At least that's what happened inside the gargantuan greenhouse called Biosphere 2 after an ecological catastrophe brought the ambitious experiment to its knees.

By Dawn Stover

Biosphere 2 was intended to be a miniature version of the much larger biosphere we call Earth. Stocked with thousands of plants and animals, including eight humans, this landlocked Noah's Ark set sail for a two-year voyage of discovery in 1991. But the project ran aground on bad management and a host of unforeseen environmental disasters, some of which are only now coming to light.

But with an Ivy League institution and a credentialed scientist at the helm, Biosphere 2 is now headed in a new direction. In January 1996, owner Edward P. Bass hired Columbia University to take over management of the beleaguered project. And last October, William C. Harris left a high-level position at the National Science Foundation to become executive director of the Biosphere 2 Center.

Columbia plans to use Biosphere 2 as a campus for the study of environmental problems such as global warming. Where better to learn about the



Tropical Hangout
THE BIOSPHERE'S glass roof soars 85 feet above the rain forest, where trees poke through the mist surrounding a miniature man-made mountain. Scientists are considering whether to build a partition between the rain forest and other "wilderness" areas.

Underwater World
THE MILLION-gallon ocean may become Arizona's first public aquarium. A large viewing window already allows visitors to peer at fish swimming around a coral reef. Engineers are grappling with ways to prevent salt and moisture from corroding the building's space frame.

A History of the Biosphere from Birth to Rebirth

November 1986

GROUND breaking for the construction of Biosphere 2. Owner Edward P. Bass, a Texas billionaire, eventually spends an estimated $200 million on design and construction of the project.

September 1991

A CREW of eight Biospherians enters through the airlock for a two-year stay. Just before "closure," engineers install scrubbers to remove excess carbon dioxide from the atmosphere.

August 1992

A SCIENTIFIC advisory committee set up by Bass recommends hiring a scientific director to oversee experiments inside the Biosphere, designing a formal research plan, and sharing experimental data with researchers at other institutions.

A Ship That Fools

Stealth technology takes to the sea in a small man-of-war.

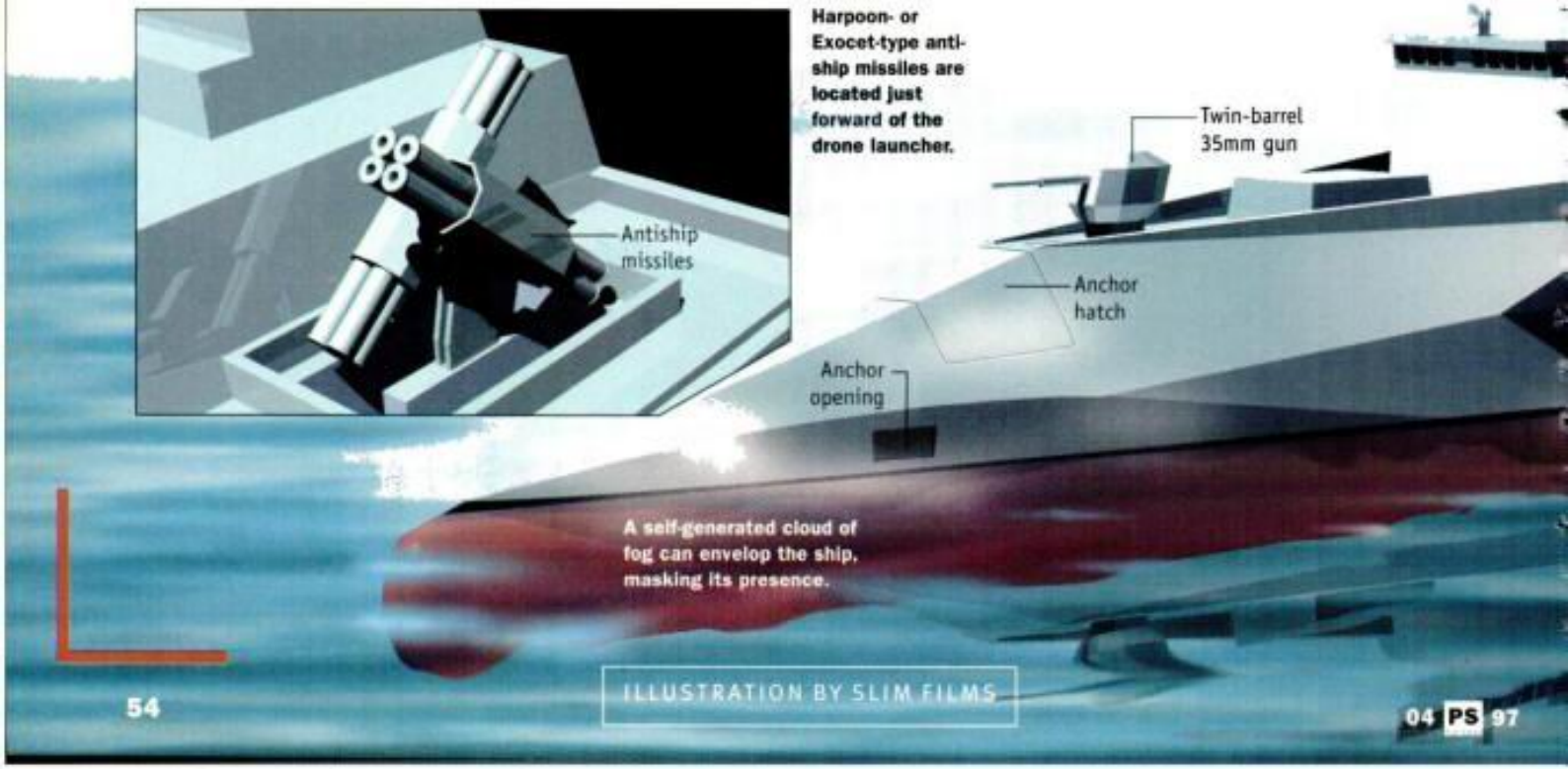
By Bill Sweetman

FAR ABOVE A TROPICAL OCEAN, during a gray dawn, the crew of a patrol airplane searches wearily for a warship that they know is out there somewhere. The plane's sophisticated radar has come up blank and confused. Once, the crew thought they had their quarry, but the object produced only a feeble glint on the radar screen and soon disappeared. But as the sky lightens, the radar operator finds the contact again, only a few miles away. The pilot flies toward the target, while another crew member trains a sensitive infrared detector in its direction. At maximum range, the sensor picks up the outline of a ship—and it vanishes once again. In disbelief, the IR operator turns to look out a window: Not a cloud is in the sky, not a trace of fog on the ocean, apart from a few wisps of morning sea-mist. They're tracking a ghost ship.

Meanwhile, a small patch of mist makes a quiet, slow exit upwind toward the horizon. This isn't sea-mist—it's an artificial fog, made with sea water, that envelops a strangely shaped warship. The cold sea water has canceled out the ship's heat radiation, leaving the enemy airplane's IR sensor blank. The artificial fog generated by the ship is one of many unusual features of the *Sea Wraith*, a very stealthy ship that might be considered a cross between an early 20th century dreadnought and an F-117 fighter.

The *Sea Wraith*, designed by English shipbuilder Vosper Thornycroft to replace the small frigates the company built for export in the 1970s, could be in service by the early 2000s. Although the United States has led the world in applying stealth technology to military

Harpoon- or Exocet-type antiship missiles are located just forward of the drone launcher.



A self-generated cloud of fog can envelop the ship, masking its presence.

ILLUSTRATION BY SLIM FILMS

aircraft, few people realize that England has made far more progress in stealthy warships. This effort goes back a number of years. Just as the U.S. Navy was putting Lockheed's ultra-stealthy *Sea Shadow* in mothballs [see "The Secret Ship," Oct. '93], the Royal Navy designed and built the outwardly conventional but quite stealthy *Duke* frigates. This work laid the foundations for the *Sea Wraith* design.

Unlike the *Sea Shadow*, which was a prototype for a specialized air-defense vessel, the *Sea Wraith* is a small, heavily armed ship designed for a full range of post-Cold War naval operations, like protecting merchant ships, hunting submarines, providing fire support for amphibious operations, and tracking smugglers. The *Sea Wraith* has a faceted shape, like the *Sea Shadow*, but with masts and decks, the English design is more complicated. Reflective features such as radio and radar antennas, guns, and ship's boats are enclosed by faceted masts and housings or retracted into the hull—there is even a large clamshell door in the bow to cover the anchors.

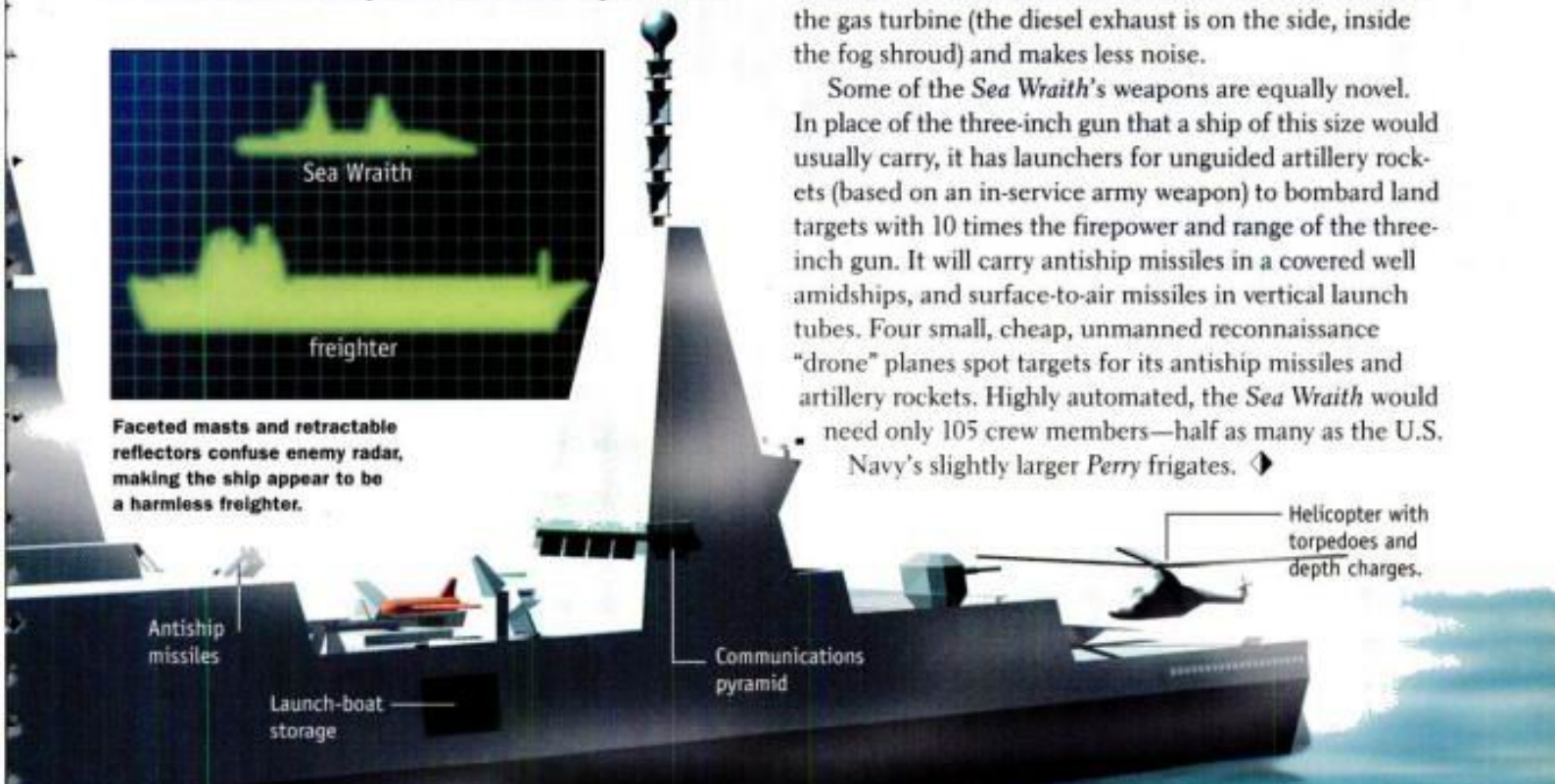
The stealth technology on the *Sea Wraith* is not designed merely to hide from enemy radars, but also to confuse them. The shape of the hull and superstructure produces many weak dual-path reflections. The *Sea Wraith* can also change the size and shape of its radar image by raising and lowering a set of retractable reflectors in the aft mast. Even if hostile radar detects the ship, the radar will not be able to identify the ship as the *Sea Wraith*.

The retractable reflectors also prevent potential enemies from seeing the *Sea Wraith*'s stealth-mode radar image. Most anti-ship missiles have radar seekers that aim at the middle of a target: the *Sea Wraith*'s two masts, one offset to port and the other to starboard, create ambiguous reflections and baffle the missile's targeting system, so that it sees a target that changes rapidly in size and location.

The designers have not forgotten infrared sensors that identify heat emissions. Apart from the artificial fog (leave it to the English to design a ship with its own fog bank) the 2,500-ton, 377-foot-long *Sea Wraith* has a dual propulsion system. For high-speed runs at up to 28 knots, it has a regenerative gas turbine engine developed by Rolls-Royce and Northrop Grumman, with a heat exchanger that uses waste heat from the exhaust to warm the incoming air and save fuel. When stealth is important, the *Sea Wrath* uses a diesel-electric drive that emits less heat than the gas turbine (the diesel exhaust is on the side, inside the fog shroud) and makes less noise.

Some of the *Sea Wraith*'s weapons are equally novel. In place of the three-inch gun that a ship of this size would usually carry, it has launchers for unguided artillery rockets (based on an in-service army weapon) to bombard land targets with 10 times the firepower and range of the three-inch gun. It will carry antiship missiles in a covered well amidships, and surface-to-air missiles in vertical launch tubes. Four small, cheap, unmanned reconnaissance "drone" planes spot targets for its antiship missiles and artillery rockets. Highly automated, the *Sea Wraith* would need only 105 crew members—half as many as the U.S. Navy's slightly larger *Perry* frigates. ◗

Faceted masts and retractable reflectors confuse enemy radar, making the ship appear to be a harmless freighter.



Four aerial reconnaissance drones are used to spot targets at long distances.

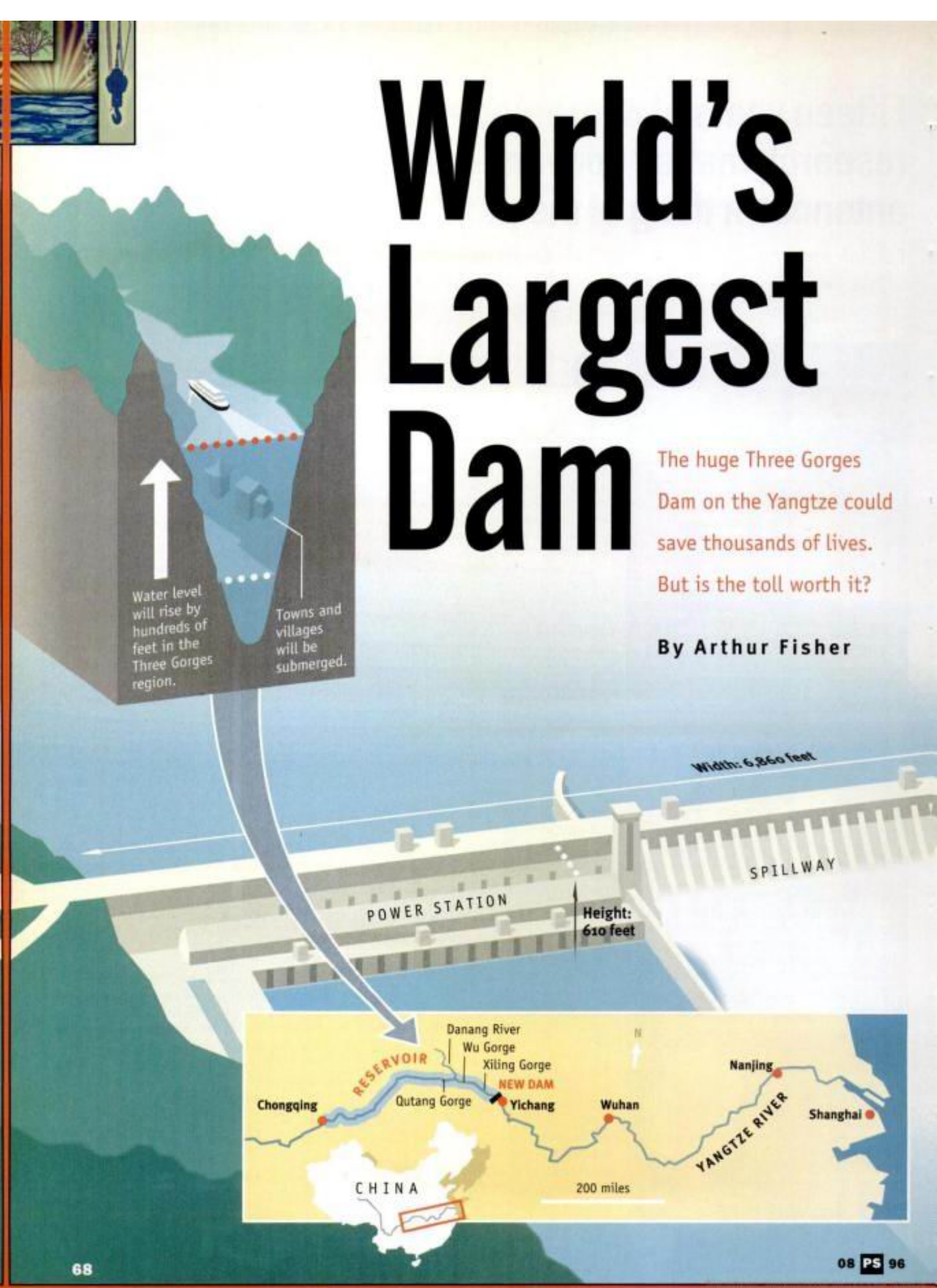
Sea Wraith

LENGTH:	115 meters
SPEED:	28 knots
RANGE:	2,500 nautical miles at 15 knots
CREW:	105
ARMAMENT:	Two medium-caliber guns; surface-to-surface missiles; rockets

World's Largest Dam

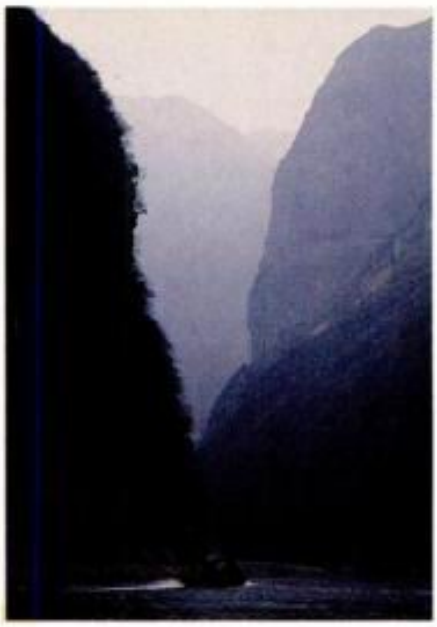
The huge Three Gorges Dam on the Yangtze could save thousands of lives. But is the toll worth it?

By Arthur Fisher



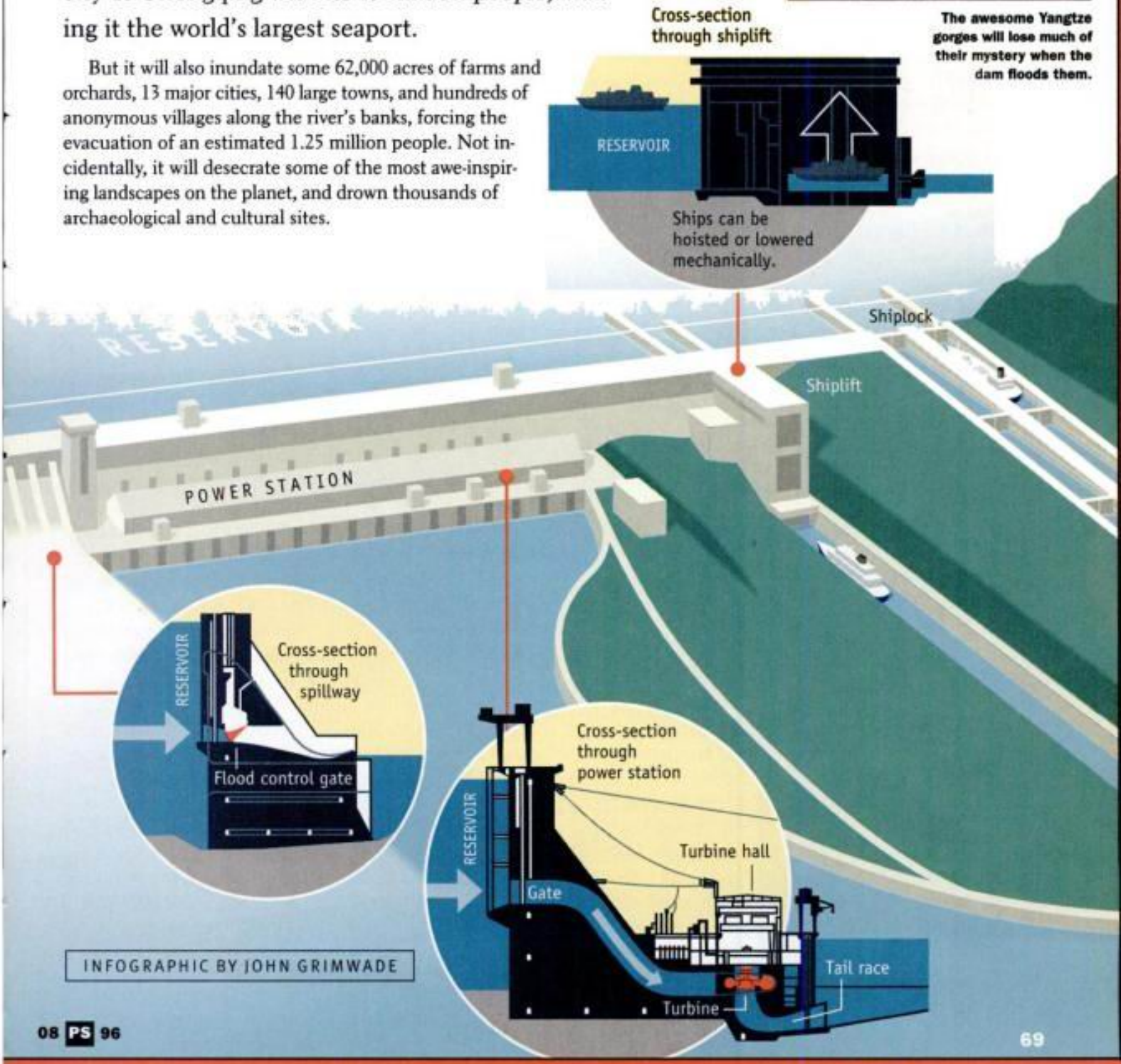
IT IS THE LARGEST ENGINEERING project on the face of the earth, and the most controversial. It aims to tame the mother of all floods, the Yangtze River, and generate 84 billion kilowatt-hours of electricity a year—enough to power much of eastern and central China. It will greatly improve navigation on the Yangtze, and create a huge, deep-water lake enabling 10,000-ton ocean-going cargo ships and passenger liners to sail 1,500 miles inland from the Pacific to the city of Chongqing with its 15 million people, making it the world's largest seaport.

But it will also inundate some 62,000 acres of farms and orchards, 13 major cities, 140 large towns, and hundreds of anonymous villages along the river's banks, forcing the evacuation of an estimated 1.25 million people. Not incidentally, it will desecrate some of the most awe-inspiring landscapes on the planet, and drown thousands of archaeological and cultural sites.



ARTHUR FISHER

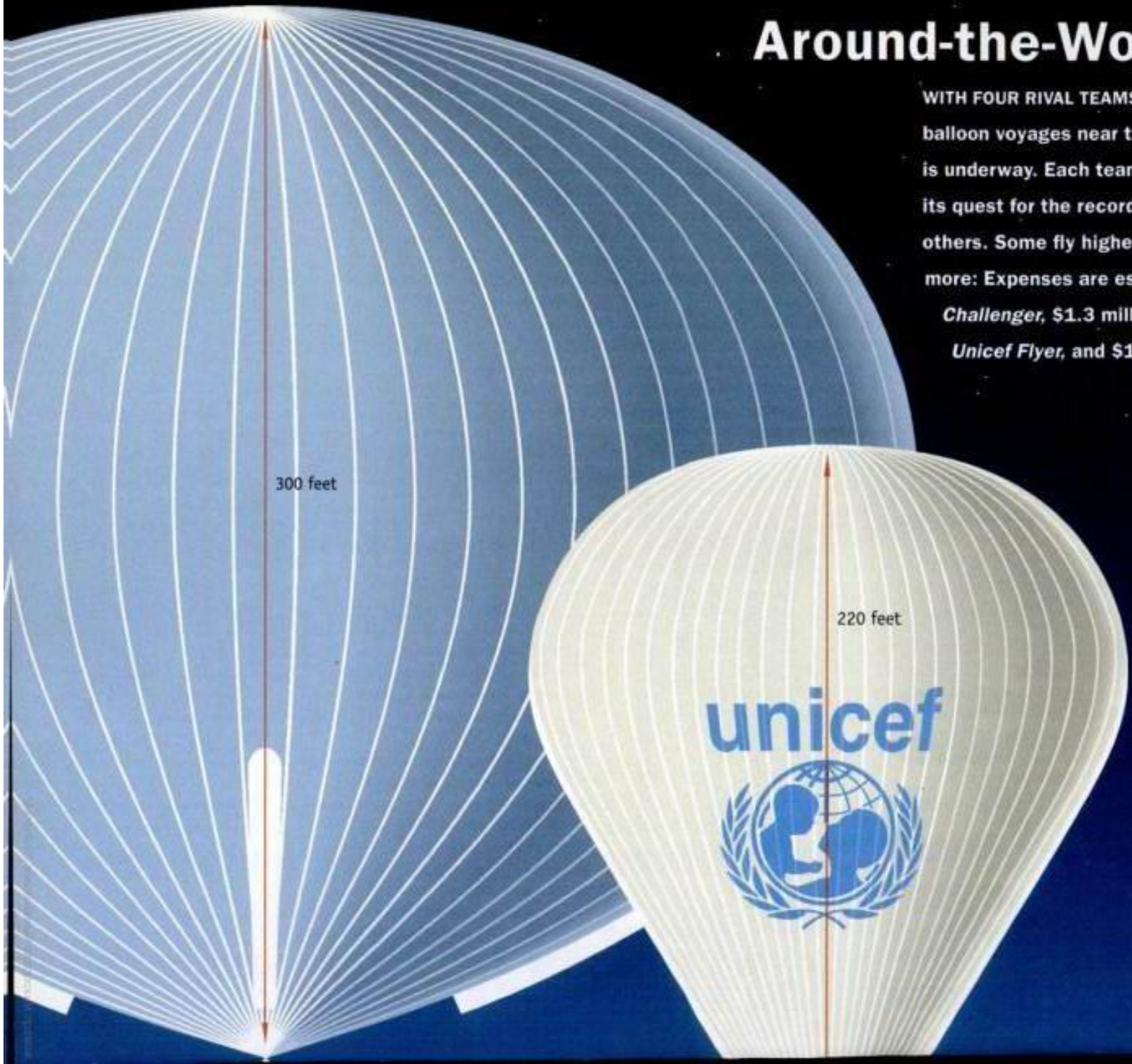
The awesome Yangtze gorges will lose much of their mystery when the dam floods them.



INFOGRAPHIC BY JOHN GRIMWADE

Around-the-World Balloons

WITH FOUR RIVAL TEAMS planning to launch globe-circling balloon voyages near the end of the year, a race of sorts is underway. Each team is using a different strategy in its quest for the record. Some balloons are larger than others. Some fly higher than others. And some cost more: Expenses are estimated at $360,000 for *Solo Challenger,* $1.3 million for *Odyssey,* $3.5 million for *Unicef Flyer,* and $10 million for *Virgin Challenger.*



Unicef Flyer

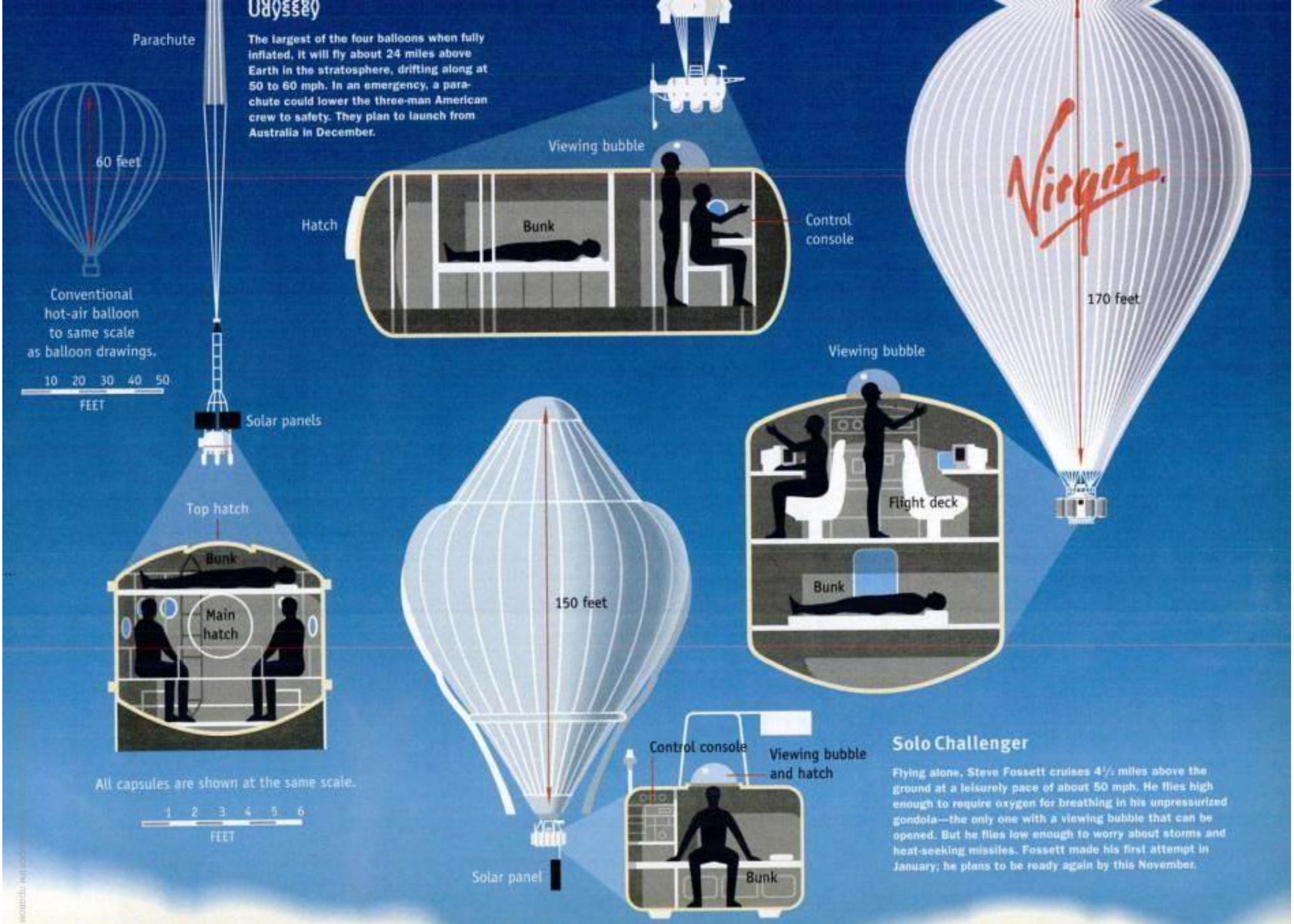
Flown by a two- or three-man Dutch team, it will hitch a ride in the jet stream, about seven miles up, zipping around the world at speeds between 100 and 250 mph. The crew plans to launch from the Netherlands sometime this winter.

Virgin Challenger

A British crew of three will also fly in the jet stream. They could experience dramatic G-forces when their balloon first hits the fast-moving air. Sponsors planned a February launch in Morocco, but the jet stream didn't cooperate. They'll try again between

Odyssey

The largest of the four balloons when fully inflated, it will fly about 24 miles above Earth in the stratosphere, drifting along at 50 to 60 mph. In an emergency, a parachute could lower the three-man American crew to safety. They plan to launch from Australia in December.



Solo Challenger

Flying alone, Steve Fossett cruises 4½ miles above the ground at a leisurely pace of about 50 mph. He flies high enough to require oxygen for breathing in his unpressurized gondola—the only one with a viewing bubble that can be opened. But he flies low enough to worry about storms and heat-seeking missiles. Fossett made his first attempt in January; he plans to be ready again by this November.

Window on the Open Ocean

By Mary Miller

GAZING THROUGH the largest window in the world, visitors to the Monterey Bay Aquarium in California now have a view of the largest ecosystem on earth.

Behind the window, which is bigger than a drive-in-movie screen, is a million-gallon tank filled with a unique assemblage of open-ocean creatures. Adapted to life without boundaries, many of the animals have never before been displayed. Aquarium visitors haven't seen it all yet, however: In 2001, a deep-sea exhibit opens in the new wing, drawing animals from the Monterey Bay Canyon—twice as deep as the Grand Canyon.

Tank within a tank
An egg-shaped fiberglass shell, supported by ribs that resemble a boat's hull, was assembled inside a large concrete rectangle, and both were filled with water. Outside the eggshell, more than 120,000 gallons of water support the thinner-walled inner tank.

Seawater

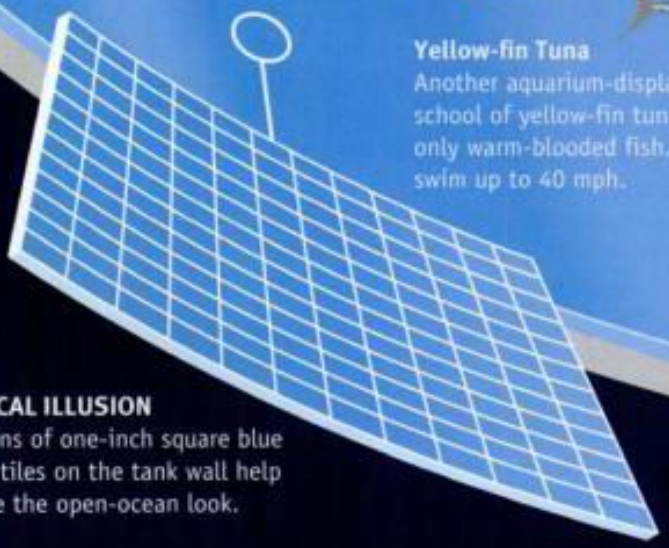
Fiberglass shell

Mola
Never permanently displayed in the United States, molas grow to 10 feet long and weigh over a ton. Molas, also called ocean sunfish, are gentle animals; they can be trained to eat out of an aquarist's hand. A group of them will politely line up and take turns feeding.

Jack Mackerel

Yellow-fin Tuna
Another aquarium-display first is the school of yellow-fin tuna, the world's only warm-blooded fish. The tuna swim up to 40 mph.

Volume: 1 million gallons of seawater.
Water weight: 8.5 million pounds.
Project cost: $57 million.
Bill for all acrylic windows: $1.8 million.



OPTICAL ILLUSION
Millions of one-inch square blue glass tiles on the tank wall help create the open-ocean look.

INFOGRAPHIC BY JOHN GRIMWADE

The fish can disappear in the distance as they sprint from one end of the giant tank to the other.

54 FEET

13 INCHES THICK

Main viewing window
The 40-ton acrylic window was shipped in five pieces from the manufacturer in Japan and bonded together on-site. To lift the completed window into place, a reinforced frame was built around a huge crane to keep the combined weight from crushing the street.

Water pressure on entire window:
2,880 pounds per square foot (about 1.5 tons), or 2,350,000 pounds (more than 1,100 tons) over the entire area.

MAIN FLOOR

17 FEET

Pacific Bonito

35 FEET DEEP

Green Sea Turtle

Soupfin Shark

Lower window

DEEP-SEA GALLERY

California Barracuda

90 FEET LONG

Supporting ribs

Filters, pumps, and heat exchangers cycle 8,000 gallons of water per minute. The system is run by a central computer that also controls lights, equipment, and heat in the new building.

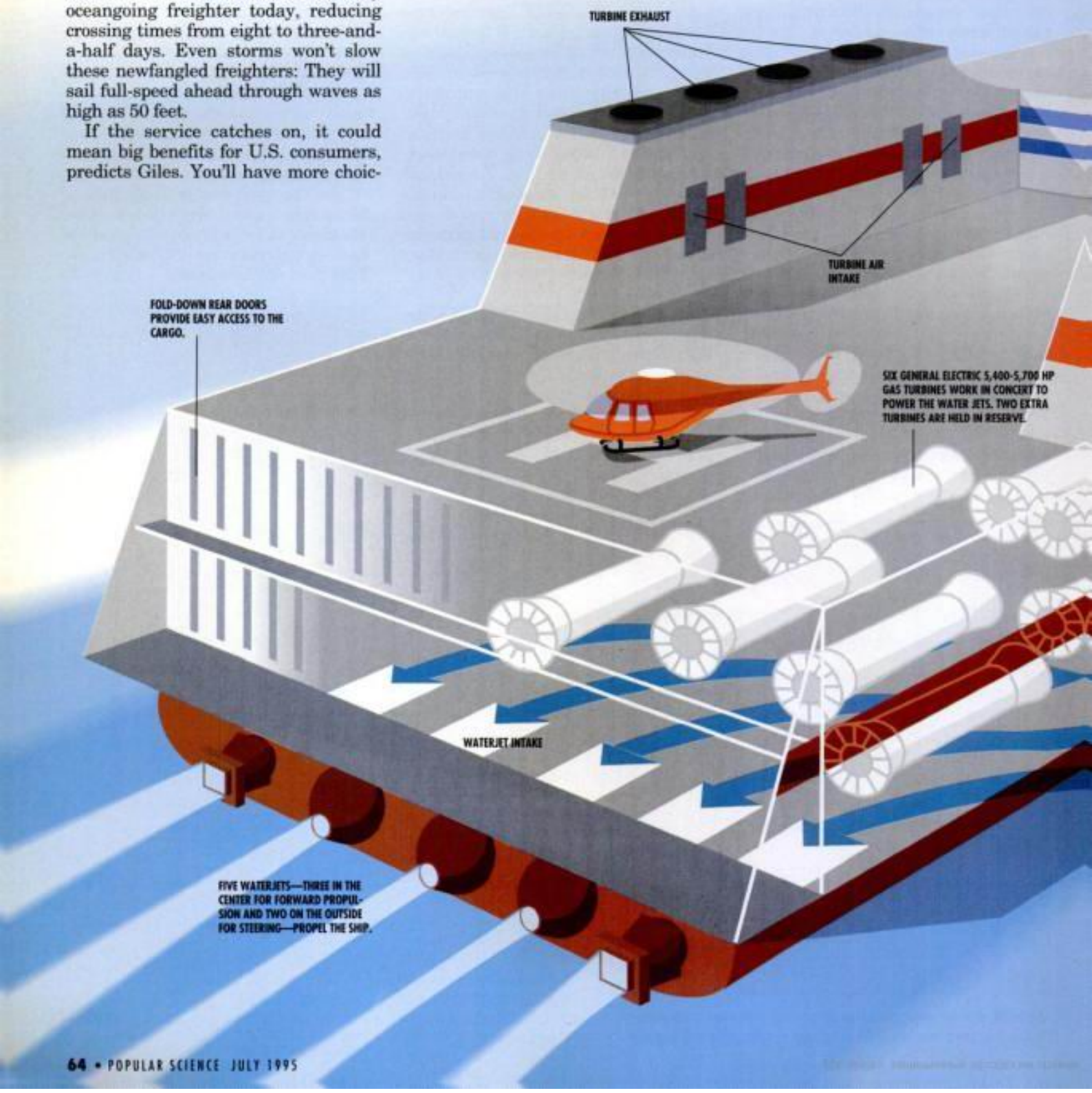
"Welcome to the jet age of cargo shipping," brags aeronautical engineer David Giles. Giles is not talking about jet aircraft, however, but cargo ships—waterjet-propelled cargo ships. The company he helped found, Fastship Atlantic Inc. of Alexandria, Va., intends to build a small fleet of such vessels by the end of the decade. Powered by giant gas turbines, the waterjets will propel 800-foot ships across the Atlantic at 35 to 40 knots—more than twice as fast as any oceangoing freighter today, reducing crossing times from eight to three-and-a-half days. Even storms won't slow these newfangled freighters: They will sail full-speed ahead through waves as high as 50 feet.

If the service catches on, it could mean big benefits for U.S. consumers, predicts Giles. You'll have more choices at the car dealer, fresher produce at your grocery store, and better prices for custom-order electronics items. Swedish carmaker Volvo—a Fastship supporter—expects Fastship to slash shipping times for its cars from 38 days to 14, for example. That should make it much more practical to order a car with the options you want, rather than just choosing from what dealers have in stock.

The secret behind the Fastship concept is the combination of waterjets and ultra-powerful gas turbines, with an unconventional hull design. Conventional ships, powered by diesel engines and propellers, cruise efficiently at speeds of approximately 18 to 24 knots. At higher speeds, a vacuum forms around propellers due to a well-known effect called cavitation, which retards forward movement. Worse, the sterns of conventionally hulled ships sink as they exceed cruising speeds, creating more drag and further reducing efficiency.

Waterjets, which don't rely on mov-

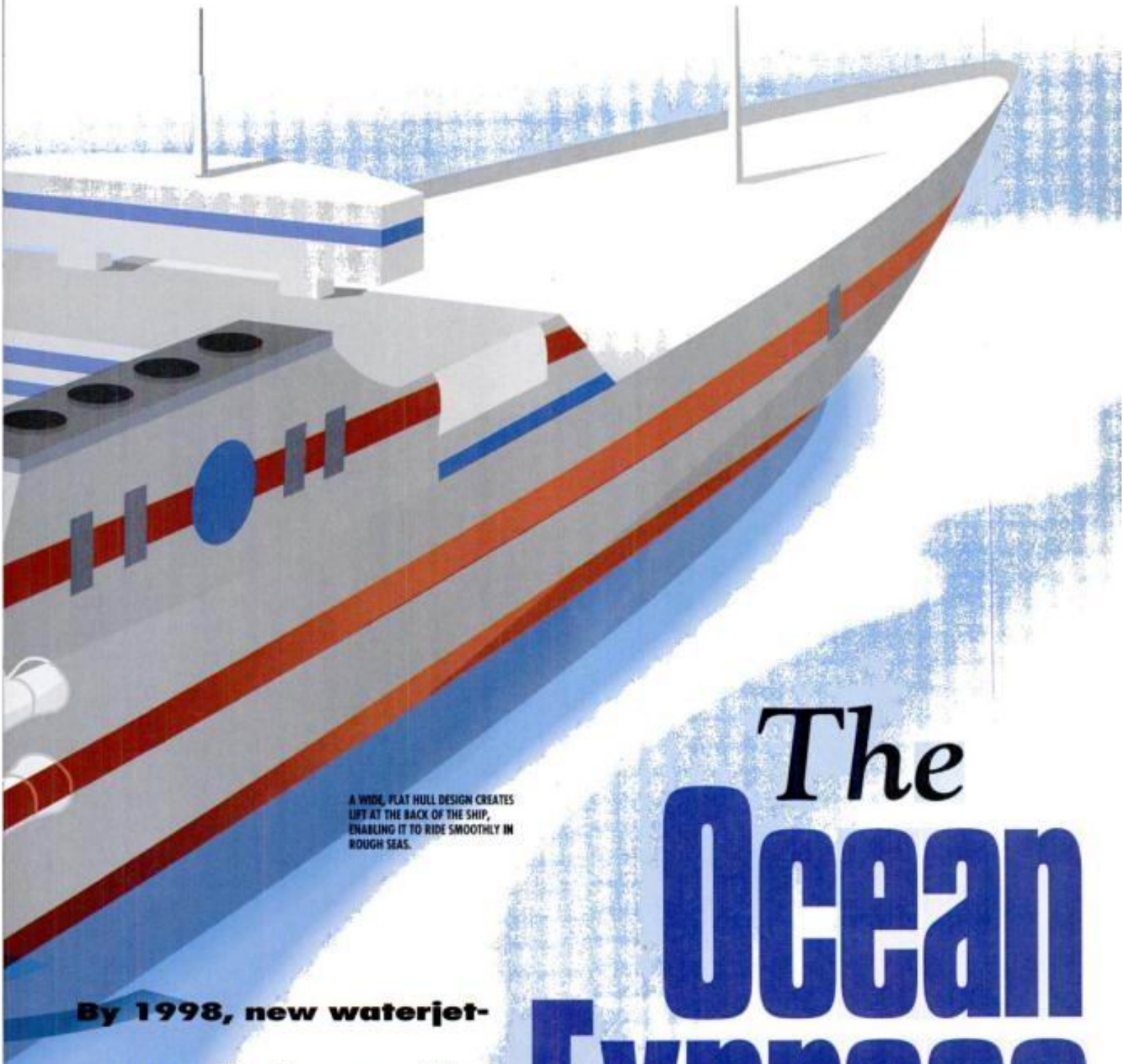
DIXON ROHR



ing parts, reach their maximum efficiency at much higher speeds. But until now, they've been limited to high-speed ferries and other relatively short transport vessels. The problem: No engines existed with the combination of size and efficiency to satisfy the enormous power requirements of ships larger than a few hundred feet. Indeed, the lack of a fuel-efficient power source has sunk many high-speed freighter proposals in the past.

But in the early 1990s General Electric crafted the LM 6000 gas tur-

[Continued on page 84]



A WIDE, FLAT HULL DESIGN CREATES LIFT AT THE BACK OF THE SHIP, ENABLING IT TO RIDE SMOOTHLY IN ROUGH SEAS.

The Ocean Express

By 1998, new waterjet-propelled cargo ships will slash ocean-crossing times in half.

BY SUZANNE KANTRA KIRSCHNER

Материал, защищенный авторским правом

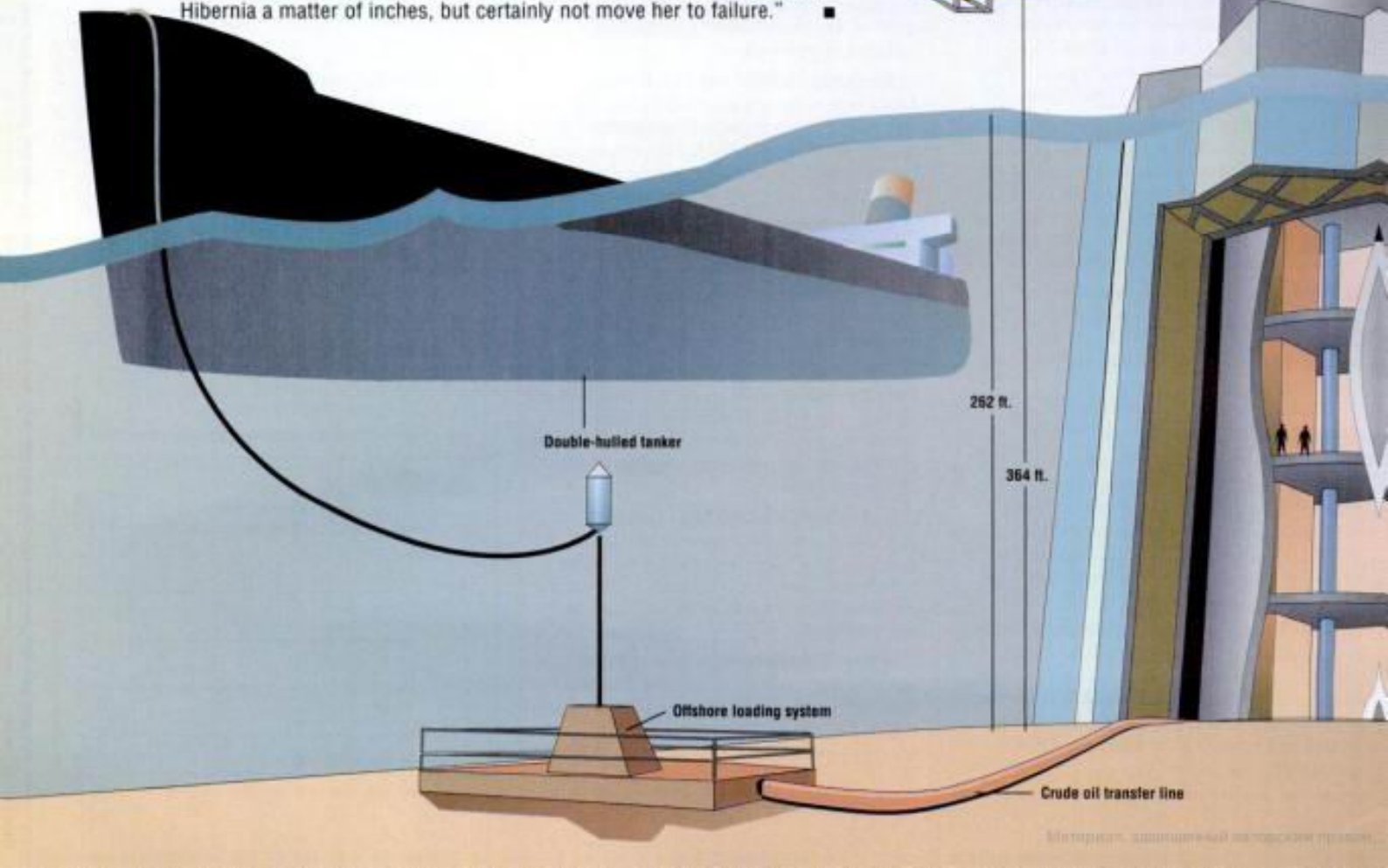
Super Structure

By Peter Britton

Two miles beneath the sea, two billion barrels of crude oil await in Newfoundland's Hibernia Field. Mobil Oil Canada plans to tap these reserves in conditions as rough as any on earth. Hibernia, the $4 billion, 1.2-million-ton monster designed to tame these waters, is the costliest and heaviest concrete oil platform ever. When it begins operation in 1997, Hibernia will contribute to the world's annual offshore crude oil production, which currently totals 6.9 billion barrels. Total annual world production is 22 billion barrels.

In a nutshell, it's big oil versus a Pandora's box of nature's extremes: wind, fog, fierce winter storms with 100-foot waves, plus a kicker no oil rig has ever faced—multimillion-ton icebergs on the move. These dreadnoughts drift down iceberg alley into the North Atlantic.

Hibernia features 16 iceberg-repelling concrete sawteeth that are designed to withstand impacts from icebergs as heavy as five million tons. Ballast keeps it anchored. Included in Mobil's plans are powerful tugs standing by to lasso threatening icebergs and tow them out of harm's way. Says Mobil engineer David Luther, "A big berg might move Hibernia a matter of inches, but certainly not move her to failure." ■



Towering 715 feet above the sea floor, Hibernia will battle winds, waves, and icebergs off the coast of Newfoundland. Two of the 60-foot-diameter support shafts hold the oil rig's planned 83 wells; the third shaft houses pipes for circulating fluids, and the fourth contains pumps. The remaining space can store 1.3 million barrels of crude. Ballast holds the entire structure in place.

The World's Oil

Largest offshore oil fields (Billion Barrels of Oil):

Arctic (Russia): 95 BBO
Campos Basin (Brazil): 11 BBO
Gulf of Mexico (U.S.): 5 BBO

Estimated percent of world's oil reserves in offshore fields: 25 to 28
Total proven world oil reserves: 1,000 BBO
Total annual world production: 22 BBO
Estimated number of years of oil remaining at current rate of production: 45.5

Sources: U.S. Geological Survey; Oil and Gas Journal

ach, hands extended toward joystick-like controls. For visibility, there's a clear acrylic bubble. Right now, the submersibles are able to dive only to 1,000 meters. *Deep Flight-2*, a version of the craft Hawkes claims would be capable of reaching the sea's greatest depths, is on the drawing board.

Today, the number "6,000" crops up frequently in the names of vehicles. That's because roughly 97 percent of the oceans have a depth of no more than 6,000 meters (about 20,000 feet). So far, there are only five manned submersibles able to operate at this depth. They are the *Nautile* (France); the *Shinkai 6500* (Japan; a second variation is planned for dives to 11,000 meters); the *Mir I* and *Mir II* (Russia); and the *Sea Cliff* (U.S.).

Since the *Trieste*, the most dramatic uses of manned submersibles (excluding military submarines) have been the discovery and subsequent filming of some of the ocean's secret wonders. First, hydrothermal vents were discovered and filmed in the Pacific in 1977 (see "Creatures of the Thermal Vents"); then, the sunken wreck of the *Titanic* was photographed for an Imax film in 1991.

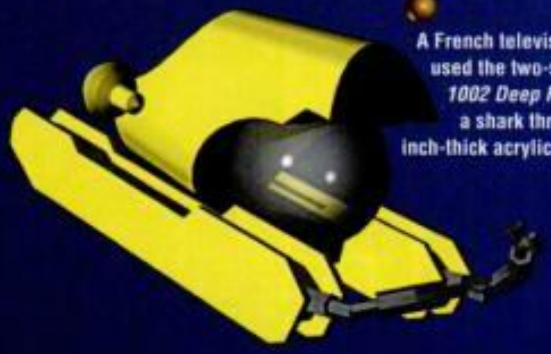
These are the high-profile jobs. But recently, one of the glamorous manned craft proved itself in a down-and-dirty industrial assignment. The *Deep Rover*, basically an acrylic bubble with strong manipulators, went tunnel inspecting. A Canadian firm fitted the vehicle with a special fiber-optic/power umbilical cord to inspect two 4.5-mile-long tunnels for the New York Power Authority's Niagara Power Project.

Remotely Operated Vehicles (ROVs) are controlled from the surface by a tether that supplies unlimited power for propulsion and tool operation, as well as audio and video communications. These ROVs can handle strenuous, continuous work with powerful manipulators, replacing and out-torquing divers on most tasks. But the tethers are unwieldy.

Through funding for research and development, the offshore oil and gas industry has figured prominently in the evolution of remotely operated vehicles—and now, ROVs figure promi-

A Flurry of Submersibles

- Manned submersibles
- Remotely operated vehicles (ROVs) use tethers (wire, fiber-optic, or acoustic)
- Autonomous underwater vehicles (AUVs) have computers on board that contain mission information



A French television crew used the two-seater *DR-1002 Deep Rover* to film a shark through its five-inch-thick acrylic sphere.

Named for the seeker of the Golden Fleece, Jason is guided from a surface ship by a pilot grasping a joystick while technicians at workstations take sonar readings and operate video and still cameras.

Vehicles such as the Auger operated by Sonsub are replacing human bell divers for servicing and repairing the sea-bottom structure of oil platforms.

A version of *Deep Flight*, a 12-foot-long "hydrobatic" ceramic vehicle, could eventually take a man to a depth of 35,800 feet.

DAVID TECH

Материал, защищенный авторским правом

The two-foot Omni Direction Intelligent Navigator (ODIN), now being tested at the University of Hawaii, moves in six directions and can hover. Once programs are downloaded, the tether is detached. A larger model is planned.

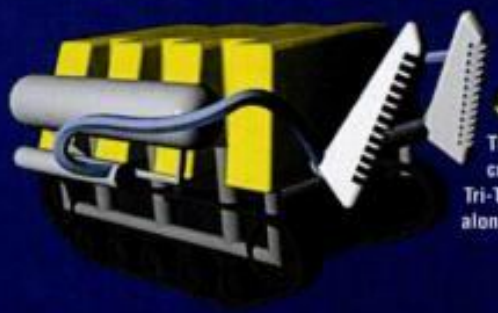
The plane-shaped ALBAC can glide at 20 degrees down from the surface to a predetermined depth. This shuttle-type AUV is from the Institute of Industrial Science, University of Tokyo.

The Probe for the Underwater Research Lab (PURL) is being tested by Simon Fraser University in Vancouver, Canada.

The autonomous EAVE III uses an acoustic telemetry program that enables it to communicate with kindred vehicles. Mission plans and obstacle avoidance are handled totally by onboard computers.

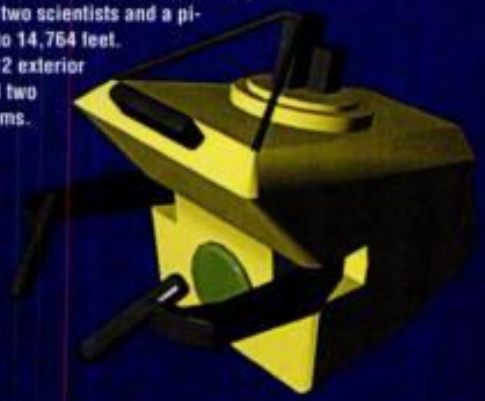
Only 61 pounds, the MiniRover MK II can operate in 1,000 feet and 1.5 knot currents. It carries a low-light, high-resolution color video camera.

After a battery explosion wrecked the NPS AUV II, the Naval Post Graduate School in Monterey, Calif., rebuilt the sharklike robot as the Phoenix. Seven feet long and 434 pounds, it's used for researching advanced control techniques.

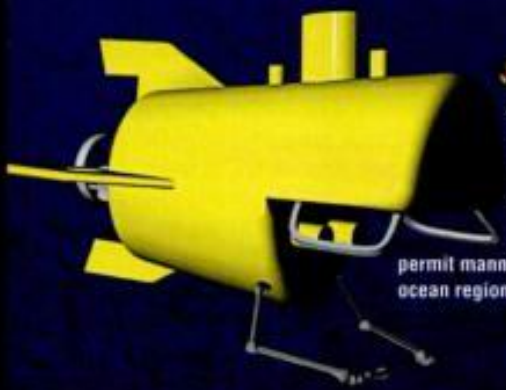


The remotely operated crawler, Trencher, from Perry Tri-Tech, could lay a pipeline along the ocean bottom.

Alvin (named for its developer, Al Vine of the Woods Hole Oceanographic Institution) can carry two scientists and a pilot down to 14,764 feet. It sports 12 exterior lights and two robotic arms.



The one-ton MT88 was developed by the Russians for locating sunken wrecks (theirs and ours). It quickly descends, follows a search pattern, photographs the object, and releases its ballast to return to the surface.



Japan's three-person *Shinkai 6500* submersible (seen here) can achieve depths of four miles. The proposed *Shinkai 11,000* would permit manned visits to the deepest ocean regions.

The torpedo-shaped Typhlonus (a streamlined version of the MT88) from the Institute for Marine Technology Problems in Vladivostok, Russia, maneuvers via an articulating tail. The name is a corruption of the word Teflon.

The Autonomous Benthic Explorer (ABE) can spend several months at a depth of 3.8 miles. It can be programmed to take daily photographs and collect data and samples within a specified area.

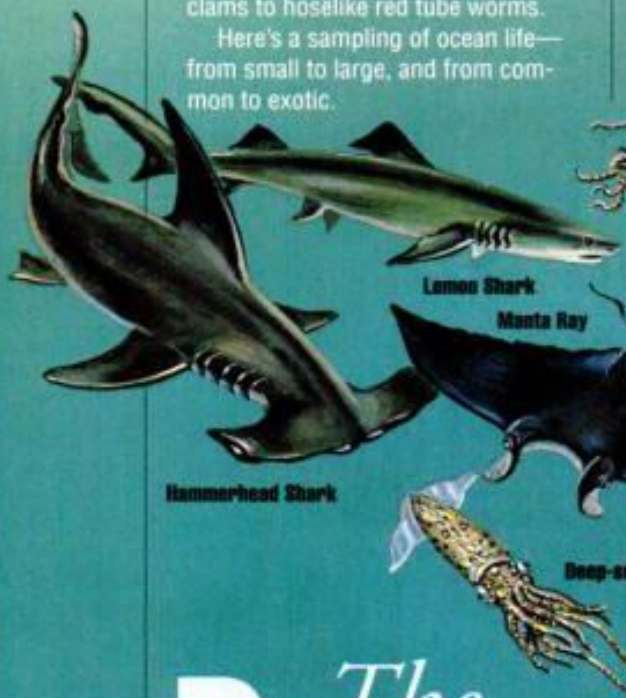
The Advanced Unmanned Search System (AUSS) is capable of inspecting the remains of an aircraft under 20,000 feet of water and sending sonar and optical images back to its mother ship.

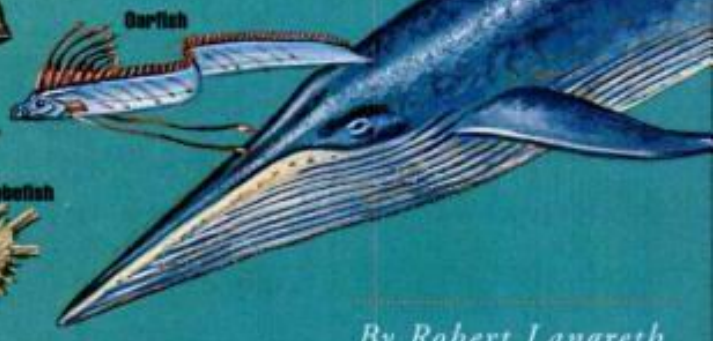
Материал, защищенный авторским правом

The oceans harbor at least as great a variety of life as do the lands. An estimated five million species, most of which have not yet been classified, reside beneath the waves. The web of marine life starts with the tiny phytoplankton—unicellular plants that are eaten by the slightly larger zooplankton, young shrimp, and other small animals. Moving up the food chain we find sponges, corals, mollusks, and other sedentary animals; then mobile creatures, including hard-shelled crustaceans; soft-bodied squids and jellyfish; eels and snakes; and small fish. At the top, of course, lurk large predators like killer whales, swordfish, and sharks.

The densest life exists in the first 200 meters of water. Below this, little light penetrates and the population density declines sharply. However, the *diversity* of life remains great even on the ocean floor, where explorers have discovered everything from giant clams to hoselike red tube worms.

Here's a sampling of ocean life—from small to large, and from common to exotic.

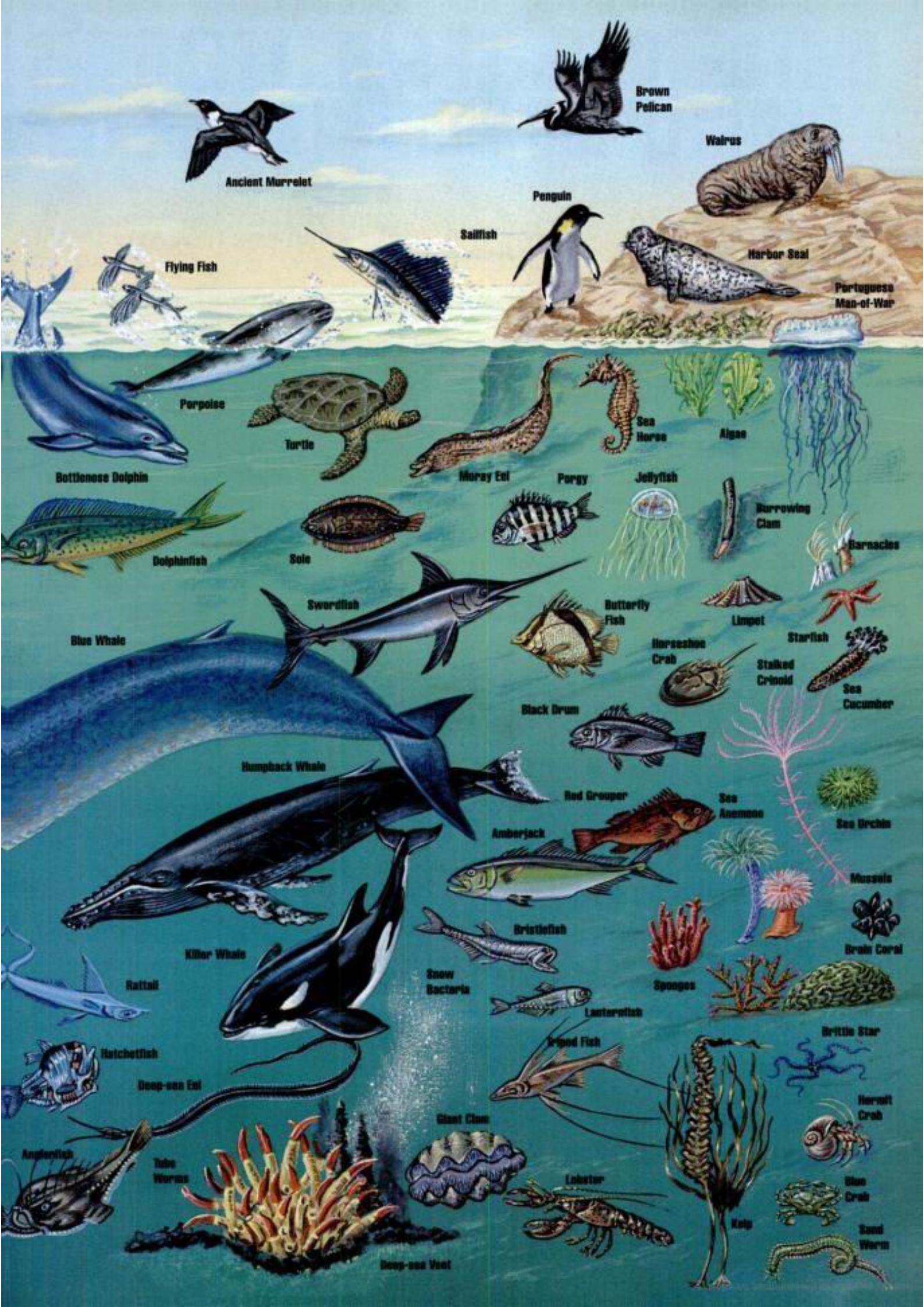




By Robert Langreth

The Diversity *of the* Sea

HOWARD S. FRIEDMAN


Brown Pelican
Ancient Murrelet
Wairus
Penguin
Sailfish
Flying Fish
Harbor Seal
Portuguese Man-of-War
Porpoise
Turtle
Sea Horse
Algae
Bottlenose Dolphin
Moray Eel
Porgy
Jellyfish
Burrowing Clam
Dolphinfish
Sole
Barnacles
Swordfish
Butterfly Fish
Limpet
Starfish
Blue Whale
Horseshoe Crab
Stalked Crinoid
Sea Cucumber
Black Drum
Humpback Whale
Red Grouper
Sea Anemone
Sea Urchin
Amberjack
Mussels
Bristlefish
Brain Coral
Killer Whale
Snow Bacteria
Sponges
Rattail
Lanternfish
Brittle Star
Tripod Fish
Hatchetfish
Deep-sea Eel
Hermit Crab
Giant Clam
Anglerfish
Tube Worms
Lobster
Blue Crab
Kelp
Sand Worm
Deep-sea Vent

URBAN OASIS

Air and water are

BY DENNIS NORMILE

Crowds and culture make Tokyo a dynamic and endlessly fascinating city, but the concentration of activity doesn't allow much room for nature. Pell-mell development has left Tokyo with less park space per resident than any other major capital.

So it was with open arms that residents of this bustling city recently welcomed a new pocket park. In a space that might have accommodated six cars, passersby can now find trees, shrubs, and a tiny artificial stream that together create a small patch of wilderness. Bird calls compete with the noise of the traffic just yards away.

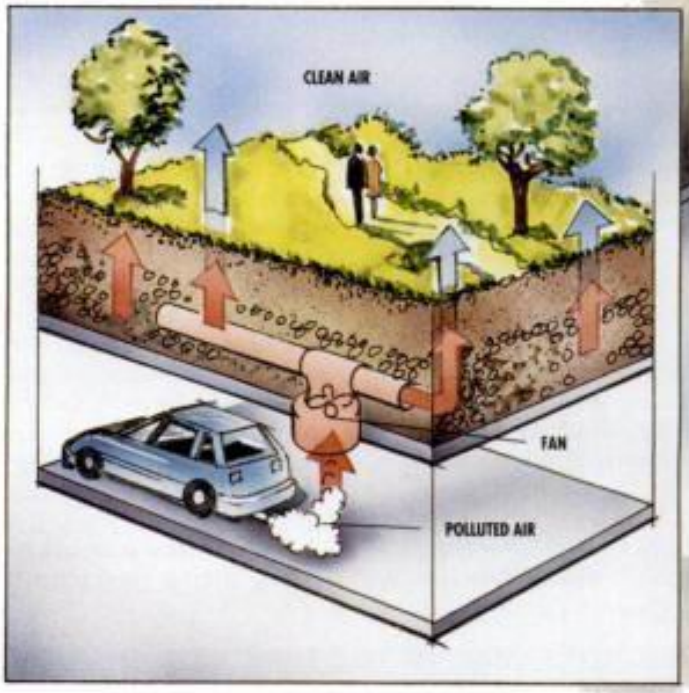
This oasis didn't happen by chance. "We wanted to show how understanding environmental cycles allows the integration of a natural environment into an urban development," says Naoaki Uchiyama, an environmental scientist who works for Fujita Corp., the construction company that built and owns the park.

The park is just one component of an office development that also includes ten- and 18-story office towers, a cafe, and public exhibit spaces. Called Urban Oasis, the project is not only Fujita's new headquarters but is also a showcase for innovative recycling schemes.

The centerpiece of the project is a network of pipes and pumps that cuts per-capita water consumption nearly in half. Rainwater collected from the roofs, and water washed down the sinks, are reused to flush toilets. The wastewater is sent to treatment tanks, where minerals and other nutrients are removed.

About 90 percent of the water taken from city supplies is reused at least once. That reduces fresh water consumption to about 13 gallons per person per day. A worker in a typical Japanese office building uses about 23 gallons per day, according to Fujita. The building also discharges about 40 percent less wastewater into

[continued on page 86]



AIR PURIFIER

To recycle air, exhaust from the underground parking garage is forced up through two soil layers and vegetation. Air pollutants such as carbon monoxide and oxides of nitrogen are taken up by microbes in the soil, and by the roots of the vegetation. Inside the lobby, air is filtered the other way: drawn down past vegetation in planters, through a soil layer, and then back into the surrounding air.

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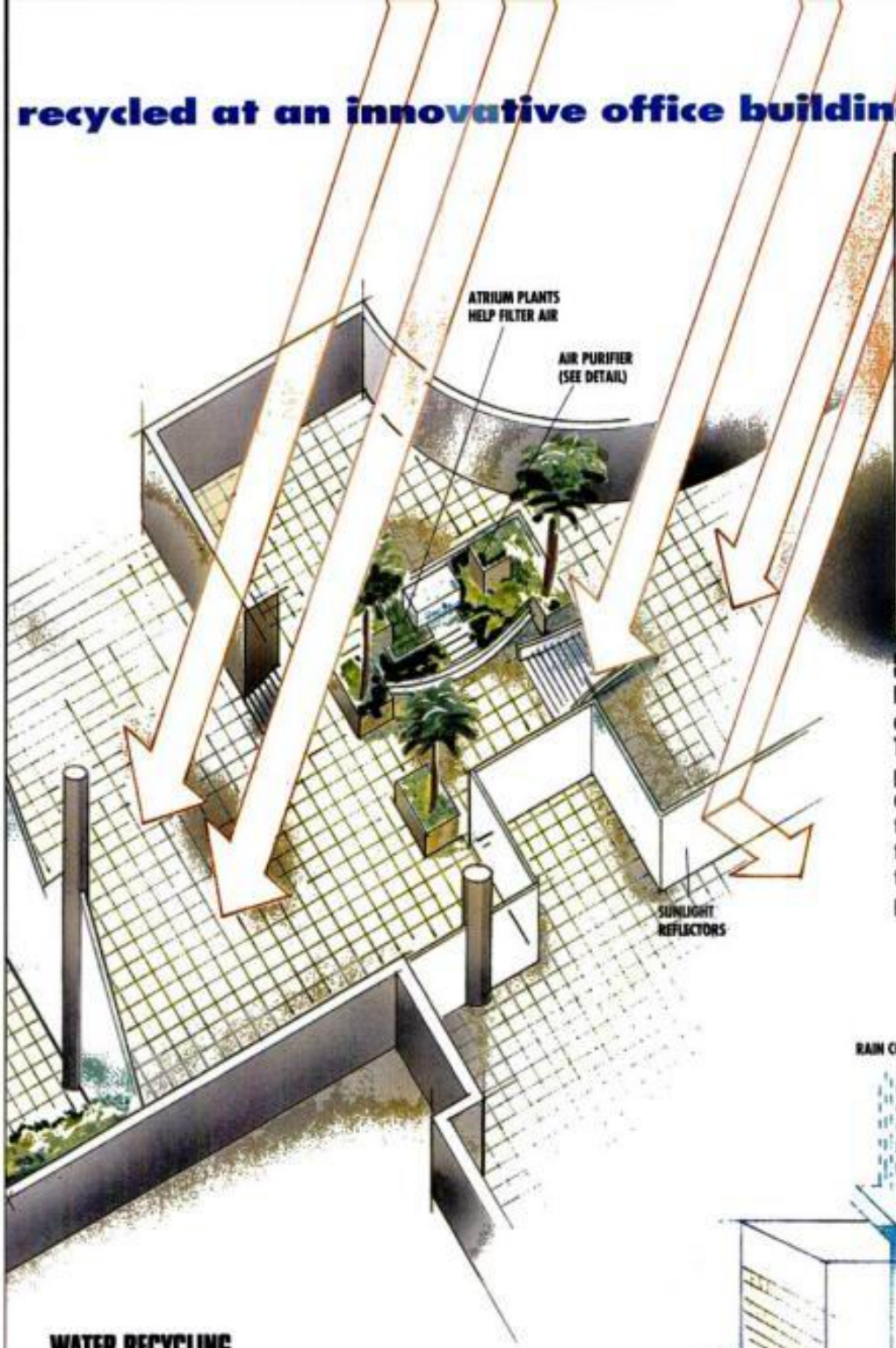
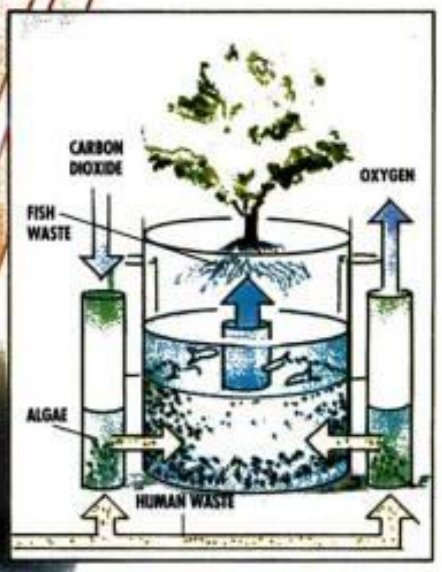
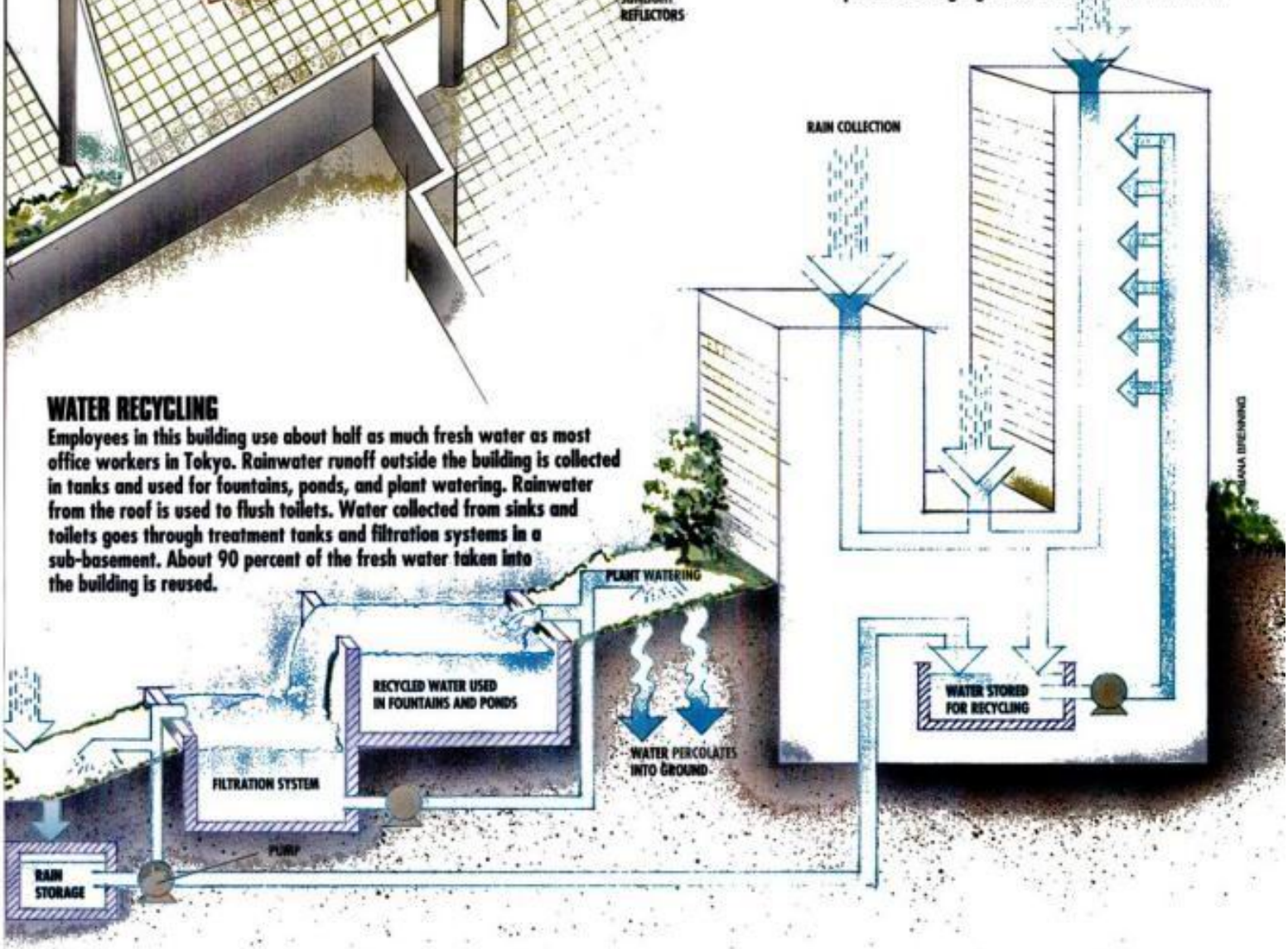
recycled at an innovative office building in Tokyo.





SUSPENDED TREE

Four cylindrical tanks, lit by fluorescent lights and filled with water, contain spirulina algae. These algae absorb nutrients from human waste pumped into the tanks. They also take up carbon dioxide and release oxygen. As they multiply, the algae spill over into an aquarium holding tilapia fish. The fish eat the algae, and the fish-tank effluent is sprayed on the roots of a camphor tree dangling in the air above the fish tank.



WATER RECYCLING

Employees in this building use about half as much fresh water as most office workers in Tokyo. Rainwater runoff outside the building is collected in tanks and used for fountains, ponds, and plant watering. Rainwater from the roof is used to flush toilets. Water collected from sinks and toilets goes through treatment tanks and filtration systems in a sub-basement. About 90 percent of the fresh water taken into the building is reused.

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DADDY LONG LEGS shuffles along with a majestic gait on four telescoping legs, avoiding the throngs of pedestrians at sidewalk level. While it offers a commanding view ahead at full extension, it can also stoop to avoid head-banging altercations with overhanging branches.

HEY! YOU TAKE THE WHEEL goes beyond the drive-by-wire concept, combining turning, accelerating, and braking into a single wireless remote-control module that replaces the steering wheel. How do you keep it from being stolen by roving joy riders? When you park, take the steering wheel with you.

PHOTOS BY JOHN B. CARNETT

In Toyota's Idea Expo vehicle competition, teams are disqualified for being too serious or practical.

FUNNY

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With driving and steering available literally for the asking at any or all of the four wheels, the **VOICE COMMAND VEHICLE** may be the ultimate parking-lot guerrilla. The biggest current hangup in development: filtering out the wishes of back-seat drivers who insist on thinking out loud.

Holy outback, Martha! It's the rarely seen mating ritual of all-terrain vehicles! With two frames and nine wheels, the **NEW WALKER** leapfrogs one set of wheels at a time to amble over obstacles or turn in its own length.

Noise pollution emitted by gridlocked drivers is converted to useful energy by the **SCREAMER**, a single-seater that regulates speed entirely by the volume of the driver's voice. It works equally well in all languages, but self-control is strongly advised.

Forget about all-wheel drive, we've got bowling-ball locomotion here! **TETRA** scoots in any direction on motor-driven spheres. A trio of support arms and fully independent drive motors eliminate the need for any sort of conventional steering mechanism.

CARS

I've always figured that if you told a group of car engineers to put all seriousness aside, they'd end up drawing computer-generated happy faces on their pocket protectors. The winning entrants in a contest for Toyota engineers and technicians disprove my theory, though, with high-smileage alternatives to everyday transportation. Toyota sponsors the contest to encourage its engineers to stretch their imagination.—*Norman S. Mayersohn*

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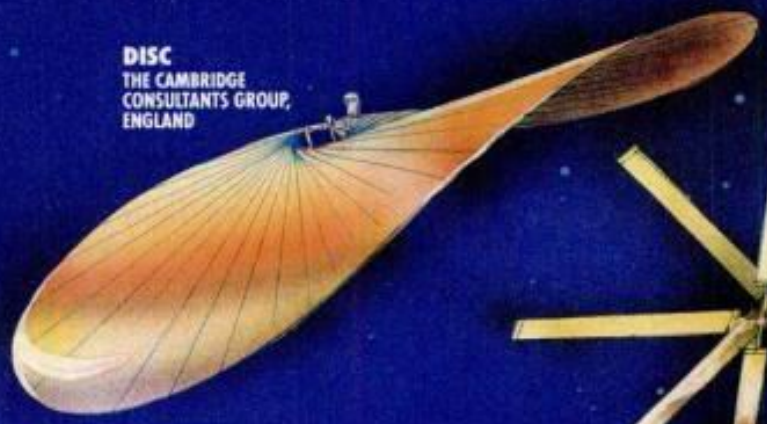

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SUNJAMMERS

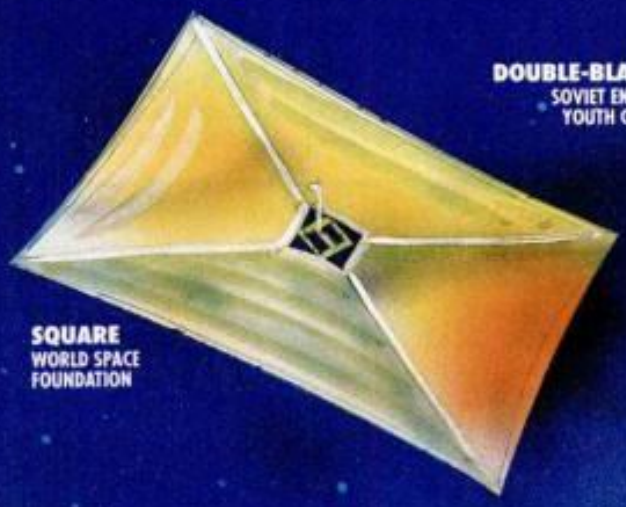
To commemorate the 500th anniversary of Christopher Columbus's voyage, the World Space Foundation, a nonprofit research group in South Pasadena, Calif., plans to send a solar-sailing spaceship to Mars in late 1992. The project's sail is a square sheet of aluminized plastic, about 175 feet on a side and 1/10,000 inch thick. "It's a mirror," explains Emerson H. LaBombard, director of the solar sail project. "The light hits the sail and bounces back, pushing it along. As long as it's exposed to sunlight, it will continue to accelerate."

The square design—vying with a variety of other shapes pictured on this page—won a competition sponsored by the Christopher Columbus Quincentenary Jubilee Commission. But the Commission isn't providing funds for the project. Building the sail will cost at least $6.5 million, LaBombard estimates. To help cut launch costs, the Foundation has teamed up with European and Japanese solar-sail researchers who have more modest ambitions: a race to the moon. The three contenders are petitioning for a ride on Europe's Ariane rocket. "All three of us are going to be bolted together," says LaBombard. After the package is released, a smaller rocket attached to the American sail will boost the trio into a higher orbit. There the sails will separate, unfurl, and begin a race to the moon. When that race ends, the American sail will continue on to Mars, a trip expected to take about three years.

The American sail will carry video and communications equipment, but its designers haven't planned any fancy experiments. "We simply want to demonstrate that this technology is a reasonable propulsion system for interplanetary travel," LaBombard says. Solar sails will never be fast enough to transport humans, but they could eventually be used as freighters to carry supplies and fuel to Mars in preparation for a manned landing.—*Dawn Stover*

HEXAGON
CANADIAN SPACE SOCIETY

DOUBLE-BLADED
SOVIET ENERGIA YOUTH CENTER



SQUARE
WORLD SPACE FOUNDATION

JANA BREDENKING

THE ANNOTATED MACHINE

ALL WING, NO NOISE

Engineers design a futuristic airliner that's easy on the environment—and your eardrums

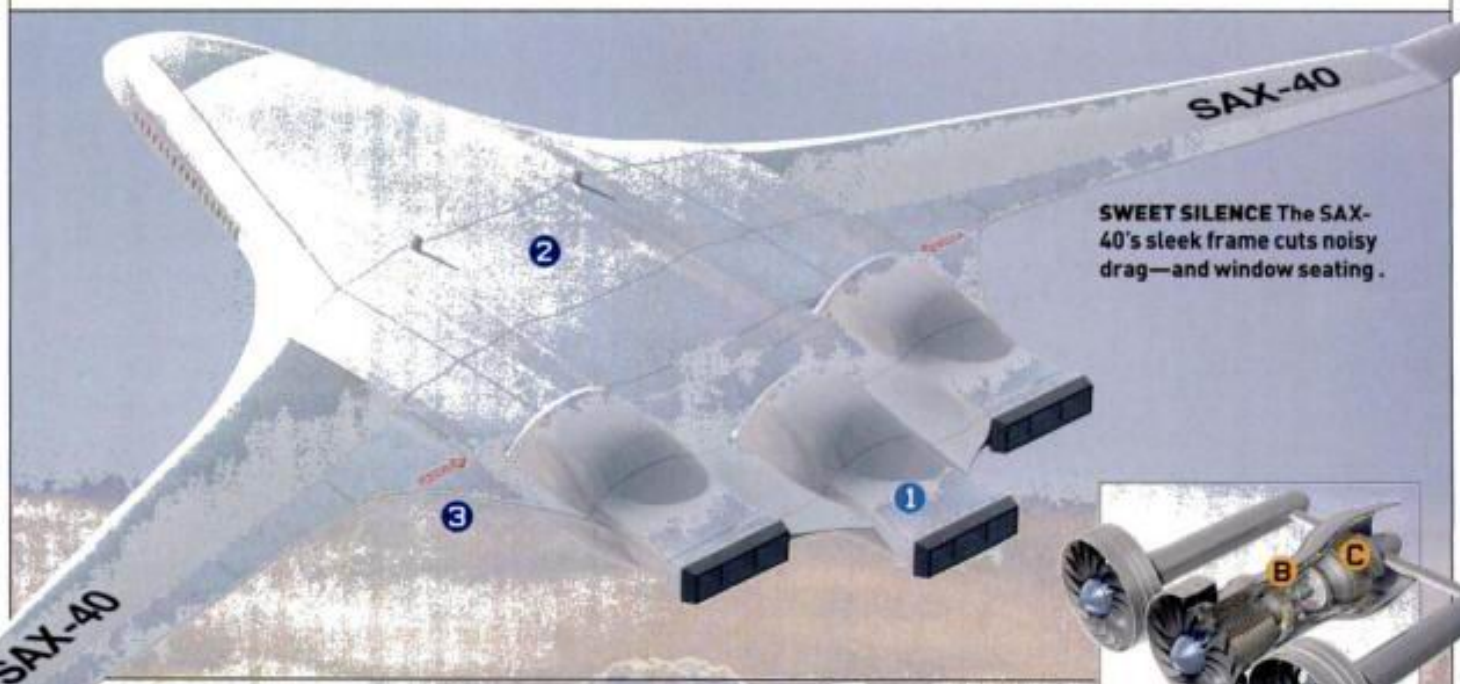
HOW WOULD YOU DESIGN an aircraft if your main aim were to keep its roar from waking up the entire neighborhood during takeoffs and landings? A group of 40 engineers from the Massachusetts Institute of Technology and England's University of Cambridge took on that challenge and, three years later, has unveiled designs for the SAX-40. Thanks to a host of noise-silencing innovations, the 215-seat airplane should be virtually inaudible outside the airport. Designers estimate that the aircraft will emit just 63 decibels at takeoff, about as loud as an average conversation. (Today's airliners hit up to150 decibels.)

To achieve such relative silence, researchers needed to rethink nearly every aspect of the typical airliner. "There's no one thing you can do," says Will Graham, who headed up the Cambridge airframe-design team. "You have to treat all the noise sources."

Chief among them is the airframe. The faster a plane flies, the louder it roars. So Graham and his group designed the SAX-40 with a blended-wing body, a concept that jettisons the tube-and-wing approach for a tailless, triangular structure. That shape provides extra lift, enabling the plane to fly more slowly during takeoff and landings. It also saves a significant amount of fuel, getting some 35 percent more passenger-miles per gallon than a Boeing 777.

A number of other researchers, including at Boeing, are working on similar concepts. But challenges remain. An aircraft without a stabilizing tail would be far more difficult to fly. And then there's the question of how to make its flattened fuselage as structurally strong as a cylinder. But perhaps the biggest hurdle is the airline industry's financial investment in conservative design. Betting on such a radical plane, Graham says, "would be a huge step for manufacturers."

—DANIEL CLERY



SWEET SILENCE The SAX-40's sleek frame cuts noisy drag—and window seating.

WHAT MAKES THE SAX-40 SO QUIET?

1. EXHAUST
The long exhaust ducts have acoustic liners to dampen noise, and the size of the exhaust nozzles can be made smaller during takeoff to reduce noise or larger while cruising for fuel efficiency.

2. AIRFRAME
Instead of noisy flaps, a sloped wing and steep landing angle do the braking. In lieu of a tail are winglet rudders. Engines embedded in the frame, with air intakes on top, reduce drag and noise.

3. WHEELS
Landing gear is the major source of noise during takeoff and touchdown. An aerodynamic fairing around the SAX-40's wheels diverts airflow and reduces drag.

4. ENGINES
Three radial-blade fans [A] per turbine [B] move large volumes of air at low, quiet speeds. Precisely tuned turbine blades [C] don't vibrate nonmoving parts.

STEVE CROSS

Материал, защищенный авторским правом

ISLAND AIRPORT

Japan's solution to airport noise and congestion: Grind up a few mountaintops, build an island, and land planes offshore 24 hours a day.

By DENNIS NORMILE

Visitors standing on the roof of the Prince Hotel in Izumisano, Japan, can see a half-built bridge reaching from the shore toward an island in Osaka Bay. But it's the island, not the bridge, that captures their attention. A few years ago, that island didn't exist. Like the bridge, it's still under construction.

At the moment, the island is little more than a giant sandbox, about 2½ miles long and ¾ mile wide. But it's slowly being transformed into Kansai International Airport, a gateway through which as many as 30 million travelers will pass each year. Covering some 1,263 acres, the island will have shops, a hotel, and even a sewage treatment plant. One of the most ambitious construction projects ever, Kansai Airport is expected to cost at least $10 billion. When the price of high-speed transportation links and coastal reclamation on the mainland are included, the project will be more expensive than the building of the tunnel under the English Channel.

Situated in the southeastern part of the bay, about three miles from shore, the airport island is at the hub of a bustling region encompassing the cities of Osaka, Kobe, and Wakayama. Ferries will carry passengers from the airport to Kobe. To reach the other cities, passengers will use the bridge, which will have an expressway for cars and buses on its upper deck and train tracks below. The trip from downtown Osaka to the airport will take less than an hour, according to Kansai International Airport Co.

Nobuyuki Higuchi, a spokesman for the Osaka-based

company, explains that the bay site was chosen largely to keep noise away from residential areas. Most of Japan's existing airports are located near densely populated cities. There's no land available for the construction of new runways, and local officials don't permit night flights. But Kansai's aircraft approach patterns will be over open water, so the airport will be allowed to operate 24 hours a day—the first to do so in Japan. Although it will have just one runway, Kansai will be able to handle as many as 160,000 takeoffs and landings a year.

Putting the airport in the bay solved noise and congestion problems, but created a host of technological problems. The biggest was how to cope with the inevitable settlement of the reclaimed land.

By June 1989, two years after construction began, workers had completed the sea wall that surrounds the island. They then began dumping rock and soil into the huge enclosure, in which the water was 59 feet deep. By the time the island is finished, workers will have transported more than 220 million cubic yards of fill to the site, enough to pack the Houston Astrodome more than 250 times.

To supply all that material, contractors are slicing off the tops of three mountains in the area. The rock is crushed into gravel, transported to shore, and barged to the site. The leveled mountains will become residential and park land.

The island is being built atop a soft, water-saturated alluvial clay layer 66 feet thick. Beneath that is a firmer diluvial clay layer approximately 1,000 feet thick. If new fill was simply

[Continued on page 90]

BUILDING THE BASEMENT

To speed the consolidation of the upper, alluvial clay layer beneath the island, engineers used three techniques: sand drains, sand compaction piles, and deep mixing.

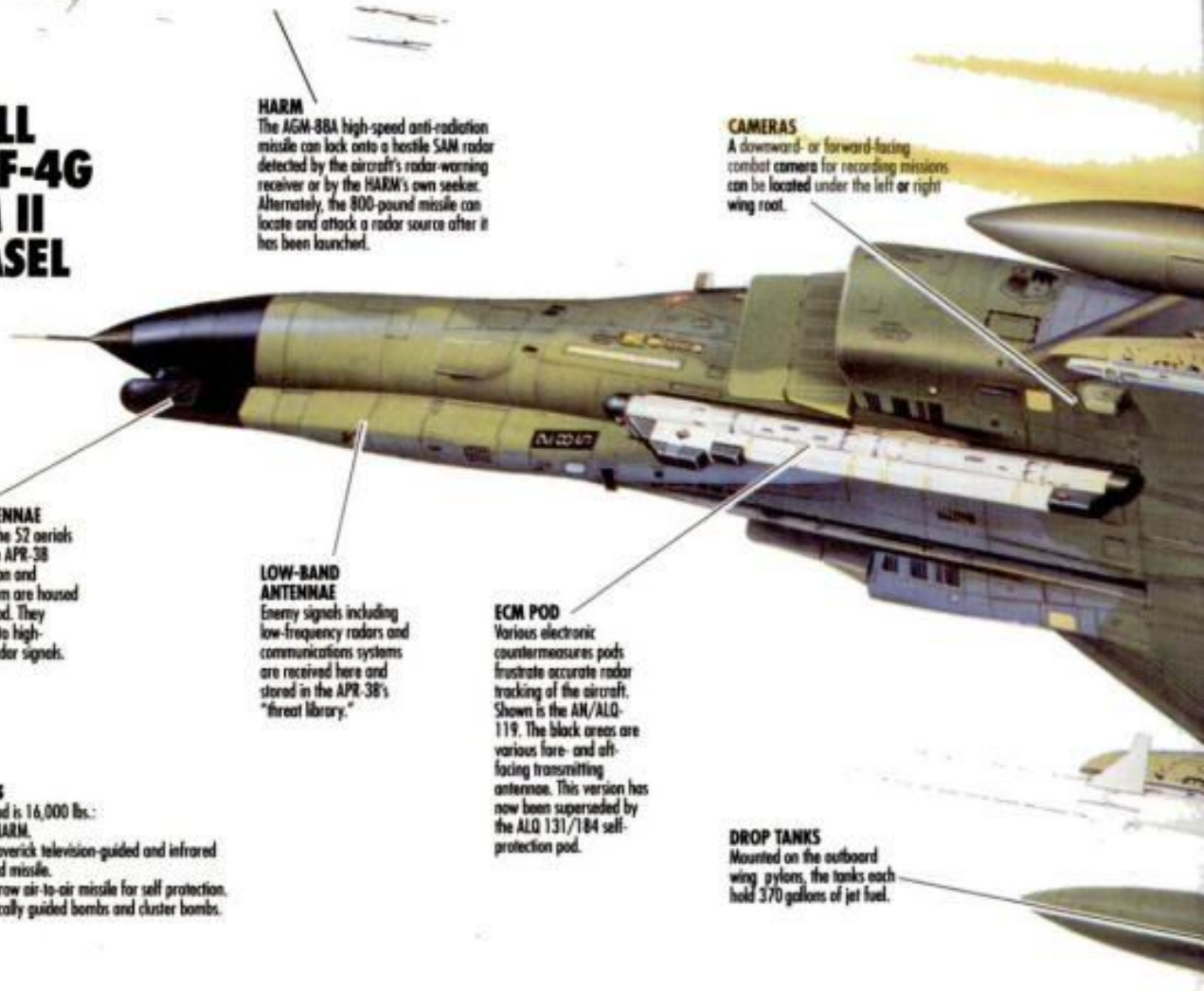
Workers installed one million sand drains (below). First they spread a 4.9-foot layer of sand over the entire site. They drove 15-inch-diameter tubes into the alluvial clay and filled them with sand. Then they withdrew the tubes, leaving shafts of sand in the clay. Squeezed out of the clay by the weight of the fill, water flows up the sand drains and out through the sand layer.

Sand compaction piles were used beneath the vertical portions of the sea wall, where ships will dock. Because the caissons forming the vertical walls are heavy, engineers strengthened the clay stratum by driving 6.6-foot-diameter casings into the clay and pouring sand into the casings, compacting it with a vibrator or a driving hammer. The piles are closely spaced to form a stiff mass of compacted clay and sand. Sand compaction piles, however, cost roughly twice as much as sand drains.

At the two corners of the island facing the sea, engineers wanted solid benchmarks for the filling operation. There they injected a cement slurry into the soil from the ends of rotating shafts. As the shafts bored into the clay, spinning paddles mixed the cement with the soil. The result was a rigid, concretelike mass. The method was too costly to use extensively.

Construction workers outlined the perimeter of the island by building a sea wall made of sand and rubble. To prevent water from washing away the wall, divers placed stones on the outward slope. Once the wall was in place, the workers then began filling in the enclosure with sand and gravel.—*D. N.*

McDONNELL DOUGLAS F-4G PHANTOM II WILD WEASEL



Loitering in the vicinity of SAM launchers for 20 minutes, and living to tell about it, is sweaty and exhausting work. "When you get near them [SAMs], you've got four to six g's on your body the whole time. You're in there turning and burning every fifteen or twenty seconds, because you can't afford to be predictable—or they'll nail you," says weasel pilot Trauernicht. "Jink and bank, climb and drop. Roll inverted, pull down, roll back out, then climb to reverse direction. This can easily become very disorienting, and it burns fuel like crazy. It's what we do to let our other airplanes get safely through to their targets."

Is this a specialty uniquely staffed by madmen? "The confidence a weasel needs to do his job doesn't come out of a sense of macho foolishness, or wanting to die," Trauernicht says. "It takes years of training flights at 500 miles per hour, right down at one hundred feet above the ground. Weaseling is a job you may be assigned to if the Air Force needs F-4G crews, and you're qualified by your flying experience."

Wild Weasel tactics were developed during the early years of U.S. involvement in Vietnam, when the Viet Cong were using new Soviet-built SAMs to shoot down airplanes in alarming numbers. The Pentagon funded a crash program to develop the first generation of radar-detection and homing equipment, which was installed in two-seat versions of the F-100 Super Sabre fighter.

The crews recruited to test the system in combat soon designed a shoulder patch featuring a cartoonish weasel above the letters YGBSM, which stood for "you gotta be sh—-ing me." It was an understandable reaction to their new job description. In 1965, these charter weasels began locating SAM sites and attacking them with unguided rockets. F-105 fighter bombers would then drop heavy bombs on the SAMs. Inventing and refining the new tactic was a horrendously risky enterprise. Of the first seven F-100 weasel aircraft, five were quickly lost along with their crews.

Soon F-105s were adapted to the leading weasel role; F-4s later replaced them. Tactics and weapons steadily evolved, and the weasel units became an integral part of bombing missions against SAM-protected targets. The crews' motto, "first in, last out," perfectly described their role as SAM-suppressors who bought the bombers relatively safe passage to their targets. "You went trolling for the SAMs. You wanted them to shoot at you," recalls former F-105 weasel pilot Paul Metz. "It's booga-booga, can you shoot me? Who-o-a-a-a....that was close! If they give themselves away, then you attack them. Weaseling is the ultimate game of chicken."

The Wild Weasels' performance in helping coalition bombers and attack planes has drawn attention to them as a common-sensical adjunct to the costly radar-foiling technology the Air Force has bet on so heavily: stealth.

Newly emboldened weasel supporters within the Pentagon and the Air Force argue that while the 118 patently unstealthy F-4Gs now in inventory may be long in the tooth and relatively expensive to operate, they are nonetheless still effective—and already paid for. So why put them out to pasture as has been proposed? Looking beyond the F-4G, tactical planners like Trauernicht envision a labor-saving single-seat Wild Weasel with artificial intelligence software and advanced cockpit displays, making the airplane more or less its own EWO. SAM designers around the world must be as busy as bees. PS

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FIN CAP
A group of mid- and high-band antennae are housed in a pod atop the vertical tail.

CHAFF AND FLARE DISPENSERS
Tracor ALE-40 countermeasures dispensers have 30 aft-firing tubes for chaff or flare cartridges. As many as eight dispensers can be mounted on the sides of the underwing pylons.

ENGINES
Two General Electric J79GE-17 turbojets, each developing 17,900 lbs. of thrust with afterburning. Maximum speed is Mach 2.27.

AFT-TIP ANTENNAE
A group of radar-warning receiver antennae monitors the hemispheric area behind the aircraft.

WING-TIP ANTENNAE
Radar-warning receivers detect hostile emitters.

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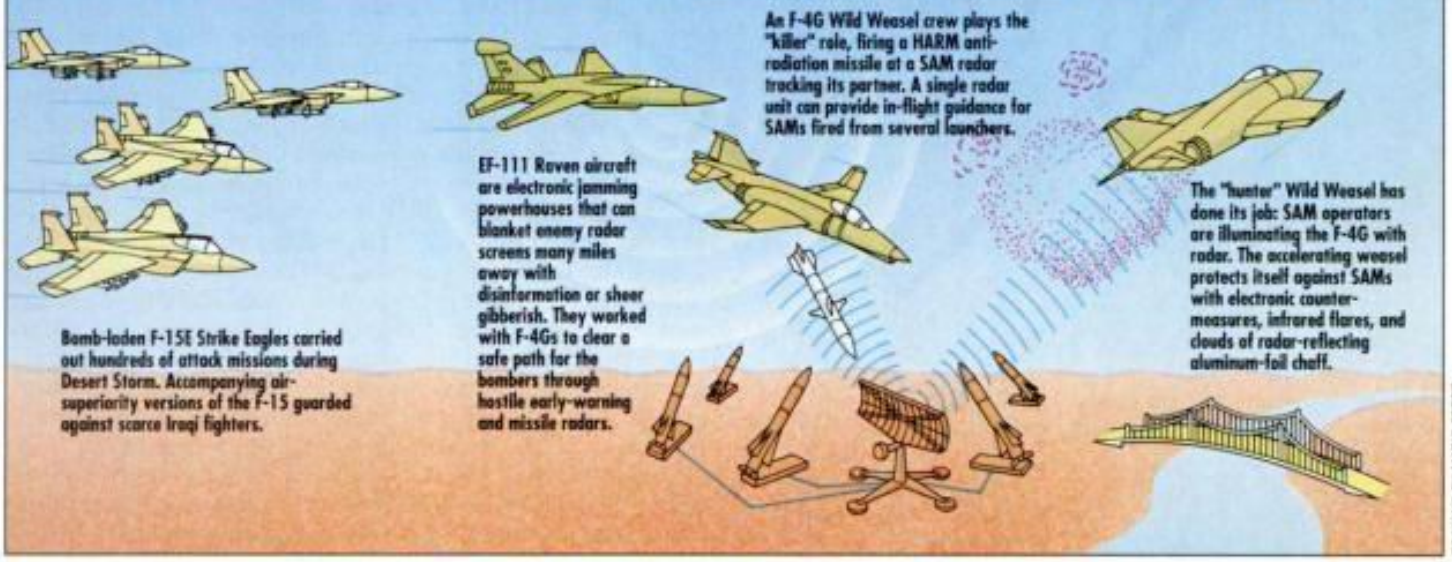
AERIAL MENAGERIE: WEASELS, RAVENS, AND EAGLES ON THE PROWL



DRAWING BY MARIO FERRO

EARTH, MY LOVE

Giant rubber bands store energy generated by photovoltaic cells in this environmentally friendly vehicle. An electric motor winds them up.

THE CLEAN ENERGY CAR

This vehicle's only emissions are oxygen and water; it's powered by a chemical reaction.

THEY JUMP THEY SPIN THEY RUN ON RUBBER BANDS

Rube Goldberg would have been proud

BY DENNIS NORMILE

A Venetian gondola that travels on dry land? A car powered by rubber bands? A commuter car that converts to a personal monorail vehicle?

It could only be the Toyota Engineering Society's annual Idea Olympics ["Funny Cars," July '90; "Automotive Newsfront," March '91]. Once again, society members have stretched their imaginations and their engineering expertise by devising improbable vehicles. But this year, even though it's all for fun, environmental interests are reflected in many of the entries.

"We're concerned about traffic jams, increasing traffic accidents, and environmental problems," explains Takeo Kurokawa, spokesperson for the team that put together Vehicle Skyner.

Much more than a car, Vehicle Skyner is a proposal for an entire transportation system. Individual electric cars would run on roads outside city centers but convert to personal monorail cars for travel downtown where a light monorail system would be strung from building to building.

The prototype is a two-wheeled vehicle with small rollers on winglike protrusions for stability on conventional roads.

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THE DELTA BEETLE

Two electric motors—one powering the triangular wheels, the other driving the tractor treads—make this car appear to be moving forward while it is actually backing up.

HAZUMU

Three sets of air pistons and springs let it jump—or dance—to its destination.

MOON WALK BICYCLE

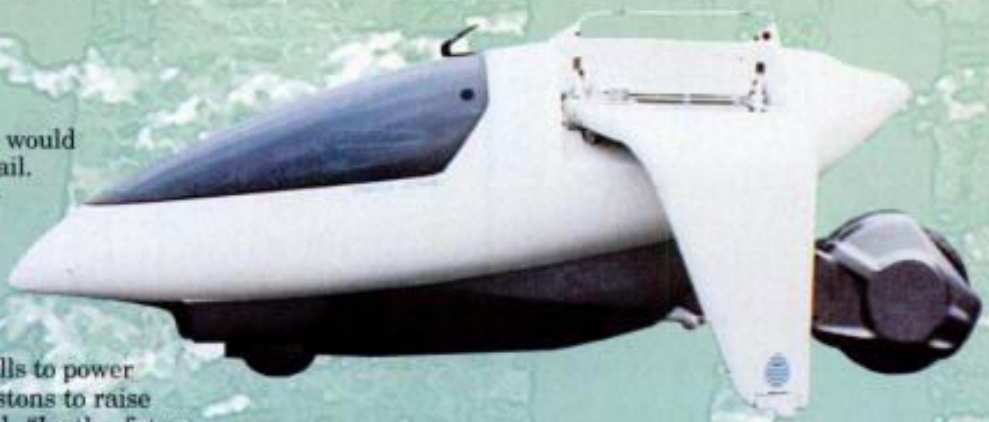
Two levers control this pedaled vehicle's motion. With both forward, it moves forward; with both back, it moves backward; with one lever forward and one back, it spins.

At a monorail entry station, the wings would swing up, allowing rollers to grasp the rail. Then the drive wheel at the rear of the vehicle would swivel up to run against the rail's bottom flange. The same drivetrain powers the car on streets and on the rail.

Power comes from conventional lead-acid batteries, but the car also has solar cells to power the controls. Compressed air drives the pistons to raise and lower the wings and the drive wheel. "In the future, maybe it could all be solar," says team member Tsuyoshi Yamazaki.

Another vehicle, the Clean Energy Car, takes a new approach to producing power. Instead of burning a fuel, it re-

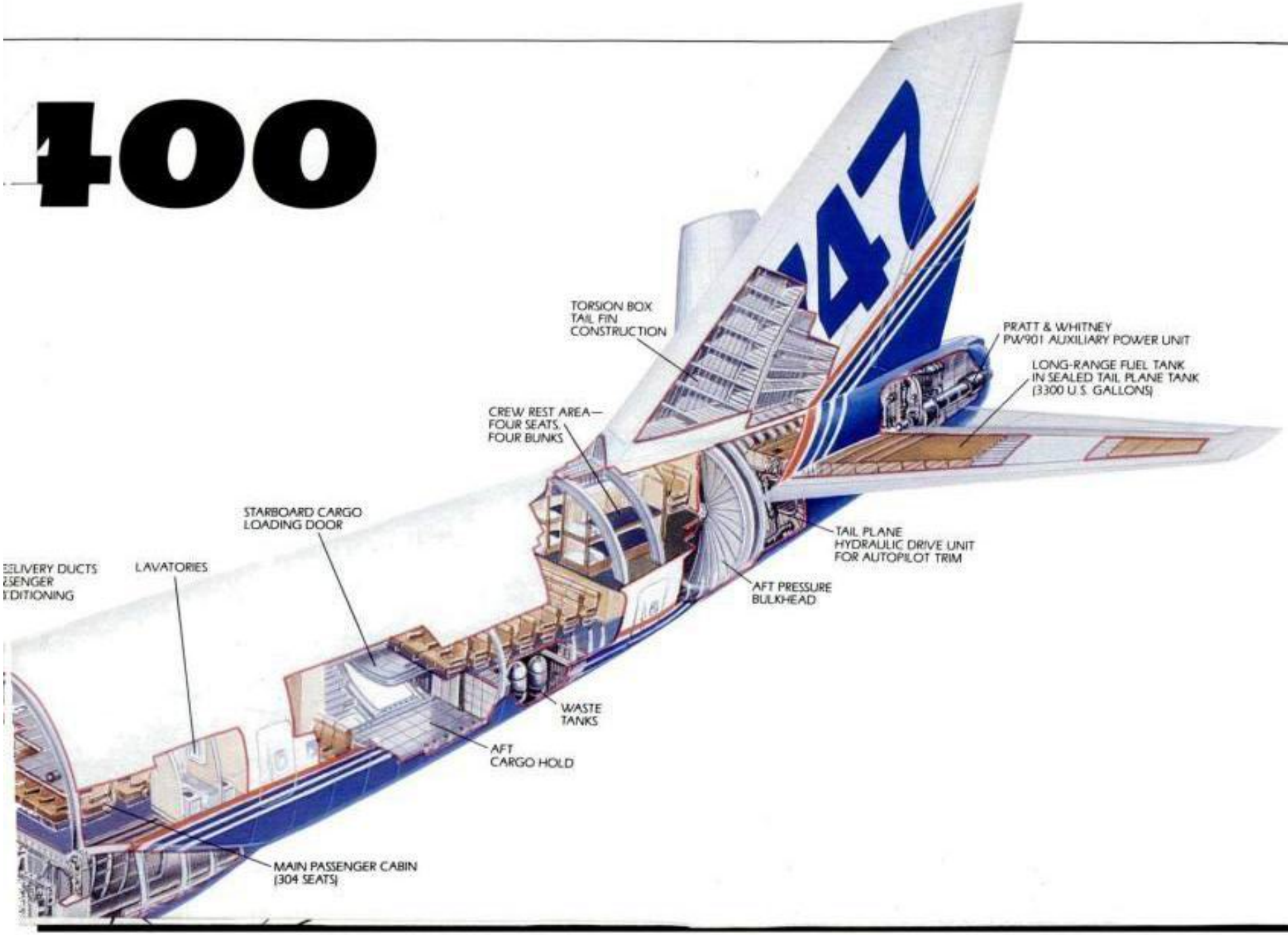
[Continued on page 94]



VEHICLE SKYNER

More than a car, it's designed as a complete transportation system. The electric vehicle would be driven on roads or on a light monorail guideway.

400



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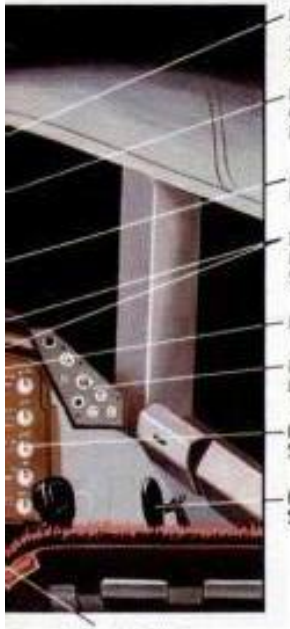

Popular Mechanics

PM ILLUSTRATIONS BY JOHN BATCHELOR

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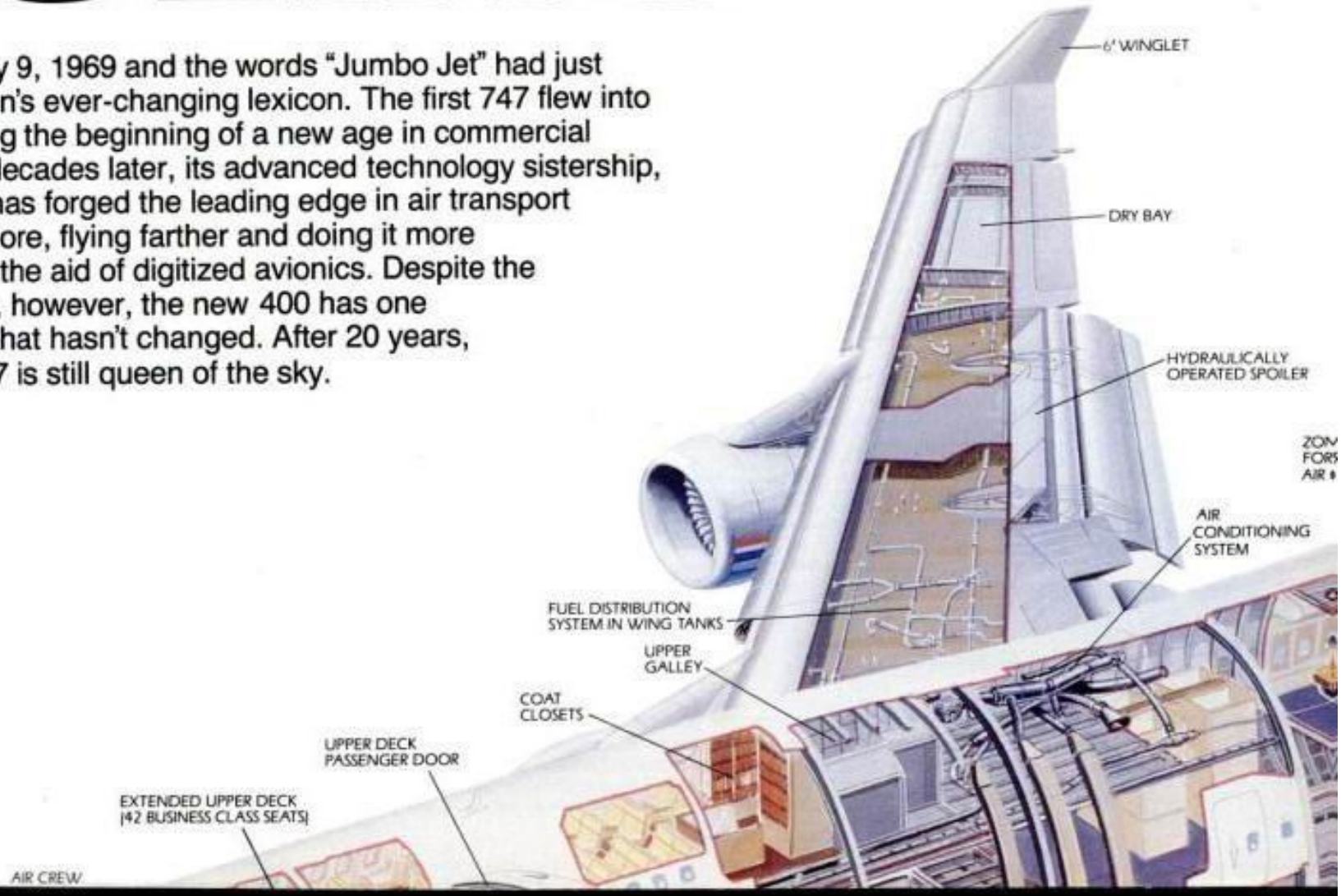
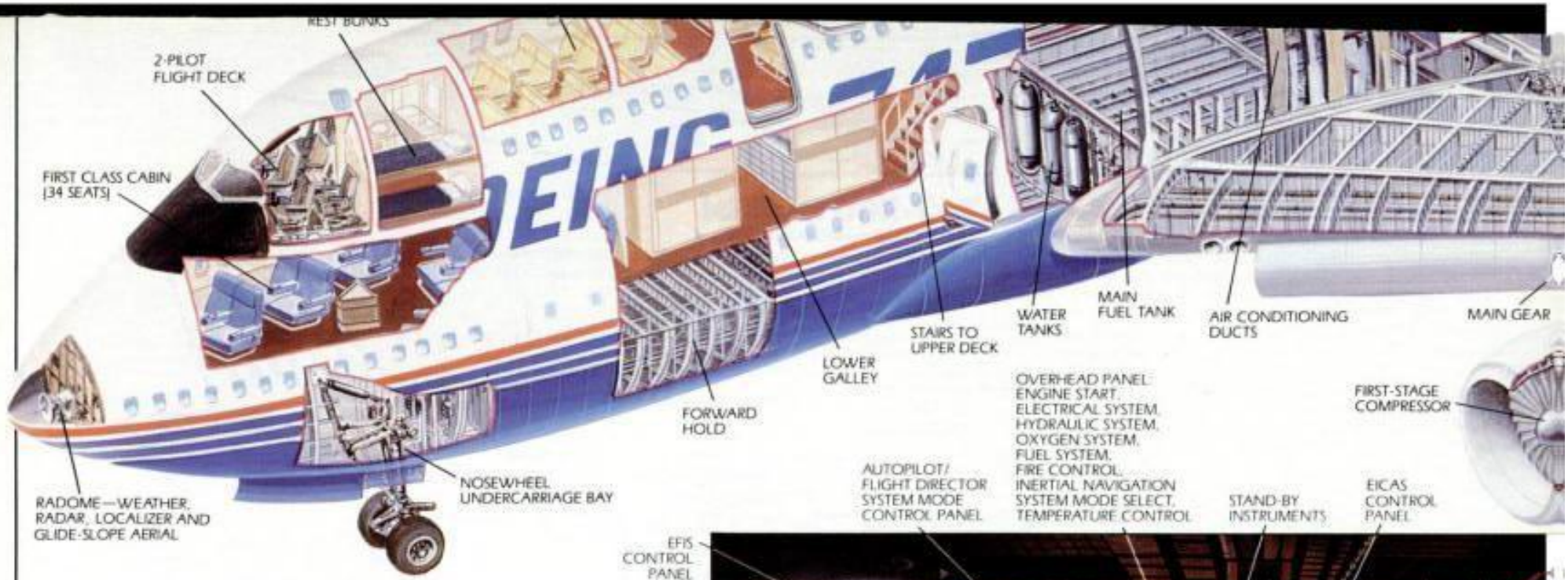
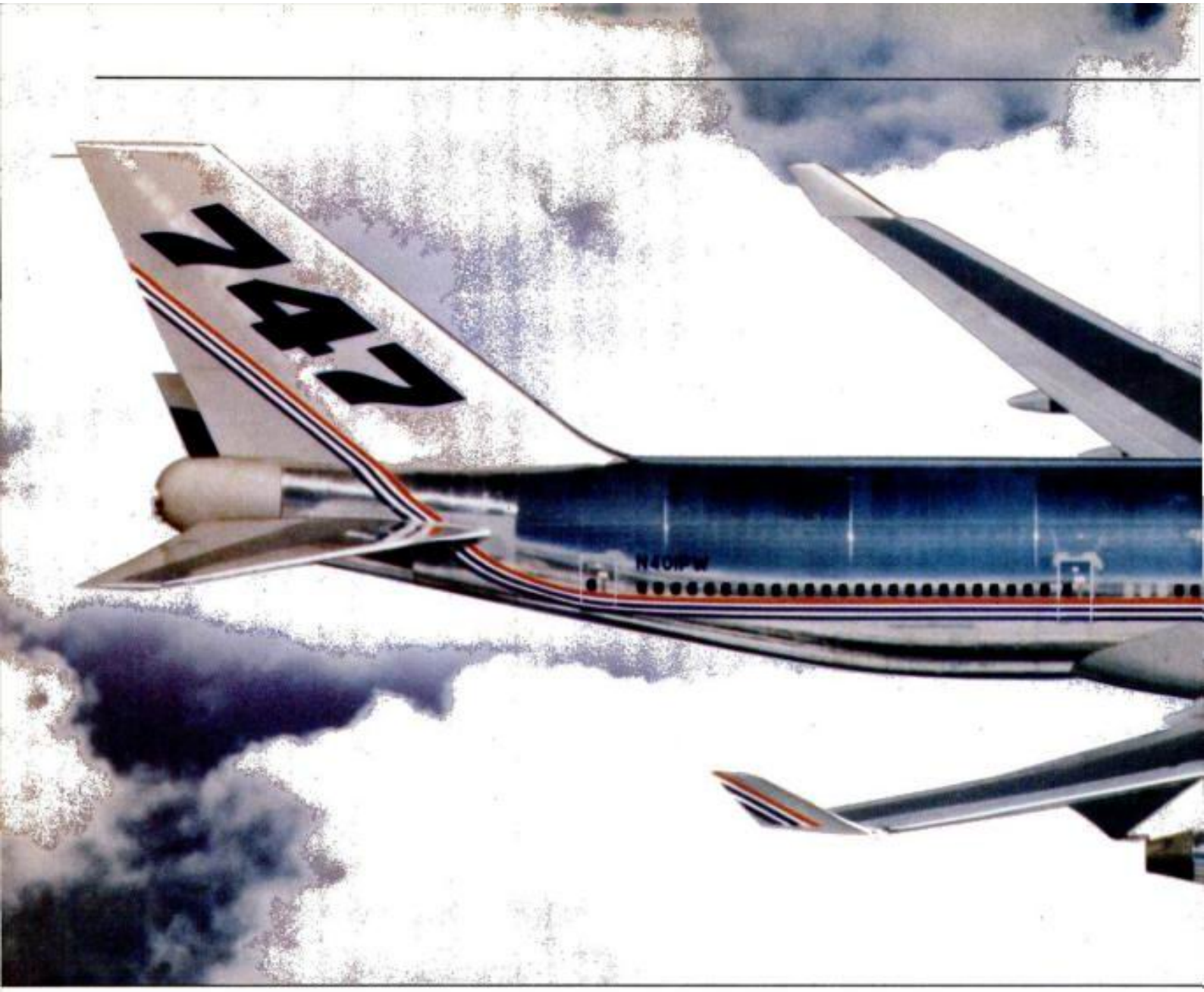
BOEING 747–

It was February 9, 1969 and the words "Jumbo Jet" had just entered aviation's ever-changing lexicon. The first 747 flew into history, marking the beginning of a new age in commercial aviation. Two decades later, its advanced technology sistership, the 747-400, has forged the leading edge in air transport tech—lifting more, flying farther and doing it more efficiently with the aid of digitized avionics. Despite the improvements, however, the new 400 has one characteristic that hasn't changed. After 20 years, the Boeing 747 is still queen of the sky.




REST BUNKS
2-PILOT FLIGHT DECK
FIRST CLASS CABIN (34 SEATS)
RADOME—WEATHER, RADAR, LOCALIZER AND GLIDE-SLOPE AERIAL
NOSEWHEEL UNDERCARRIAGE BAY
FORWARD HOLD
LOWER GALLEY
STAIRS TO UPPER DECK
WATER TANKS
MAIN FUEL TANK
AIR CONDITIONING DUCTS
MAIN GEAR
FIRST-STAGE COMPRESSOR

OVERHEAD PANEL: ENGINE START, ELECTRICAL SYSTEM, HYDRAULIC SYSTEM, OXYGEN SYSTEM, FUEL SYSTEM, FIRE CONTROL, INERTIAL NAVIGATION SYSTEM MODE SELECT, TEMPERATURE CONTROL
AUTOPILOT/ FLIGHT DIRECTOR SYSTEM MODE CONTROL PANEL
STAND-BY INSTRUMENTS
EICAS CONTROL PANEL
EFIS CONTROL PANEL
DISPLAY SWITCHING
ELECTRONIC FLIGHT INSTRUMENT SYSTEM (EFIS)
REAL-TIME CLOCK
RADIO-MAGNETIC INDICATOR
INTERNAL LIGHTING CONTROLS
INSTRUMENT SOURCE SELECTION
NOSEWHEEL STEERING TILLER
CAPTAIN'S CONTROL COLUMN
BRAKE PRESSURE INDICATOR
ELECTRONIC FLIGHT INSTRUMENT SYSTEM (EFIS)
MAINTENANCE CONTROL DISPLAY UNIT
ENGINE CONTROLS
MAINTENANCE CONTROL DISPLAY UNIT
ALTERNATE GEAR CONTROLS



ONE HUNDRED different 747s from all over the world are at New York's John F. Kennedy Airport this sparkling clear January day, but two are special. The first, with tail number N633US, is cleared onto Kennedy's longest 14,000-ft. runway. "Northwest 17, runway 31 Left, position and hold."

The pilot nudges the throttles forward, breaking the inertia of this giant weighing nearly 900,000 pounds. The aircraft carries 250,000 pounds of fuel, a full load of 402 passengers, and a belly full of baggage and freight. It creeps forward the first few feet on a journey that will cover 6300 miles and end in Tokyo, Japan, 14 hours later.

This regular daily Northwest flight will also go down in history as the first revenue movement of Boeing's latest cruise ship of the sky, the 747-400.

The second special 747 to visit JFK this morning, N733, is 10 miles southeast of the airport, 3000 ft. over the chilly Atlantic. Pan American Flight 101 from London is cleared for the approach to runway 31 Right. This 747-100, with *Clipper Pride of the Sea* emblazoned on the front of its shiny fuselage, is remarkable in its own right. It is the first 747, of the roughly 700 now in service, to be delivered to an airline. In fact, this January 1989 landing is N733's 17,000th since Pan American began operating the airplane in January, 1970.

The 747-400 bears a strong family resemblance to the pioneer 747. But from its vastly changed avionics to the very alloys it is made of, the 747-400 is a bird of a different feather. It offers more range, better fuel economy and lower operating costs than any previous 747. Its 8400-mile range almost doubles that of the original 747, and it consumes almost a third less fuel per seat. Its engines produce a fifth more power than the original, and the 400 carries more passengers and freight.

Comparing the first 747 with the newest version also provides an intriguing glimpse of aviation past and aviation future—a chance to closely analyze almost two decades of progress in the air.

Prepared for takeoff

As the Northwest captain turns the airplane to line up with 31 Left, he looks back over his shoulder 200 ft. to check clearance and sees the wingtip with its distinctive 6-ft.-high winglet sweeping the horizon. The winglet is a major element in the 400's load and range improvements. To carry the additional weight over the extended range, more lift was needed and this was accomplished by adding 6 ft. to the span of each wing.

That was about all the wings could be stretched, however, without causing operational problems at the airports the 747 flies into. Hangars, docking spaces and even runways are only so wide.

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COVER STORY

BIG BIRD

Commercial air transport takes a giant leap forward as the 747-400, with almost 1 million pounds of lift capacity, goes into service.

BY FRED MACKERODT, Contributing Editor

The winglets, jutting up an additional 6 ft. at a 29° angle from the wings, provide the additional lift without causing clearance problems. They also enhance the airplane's aerodynamics by cleaning up the wing-tip vortices, those tornadoes of air that come off the ends of all wings when they're producing lift.

In extending the wings, Boeing engineers were confronted with a problem. They knew that each 1-percent increase in weight causes a 2-percent reduction in range. By building the wings with new aluminum alloys used in the 757 and 767, and constructing the winglets out of graphite-epoxy material, they were able to save 5000 pounds, completely offsetting the weight which would have been required for the modification. The winglets provide a fuel burn improvement of about 3 percent. The 400 spans 211 ft. from wingtip to wingtip—gaining an additional 2 ft. when it is loaded with fuel.

The most significant improvement of the Boeing 747-400 can be found in the plane's "glass" cockpit, a futuristic sanctuary of multihued cathode-ray tubes. Reduced workload means that two pilots can operate the aircraft, eliminating the flight engineer's position. The key: Microprocessors have reduced the number of switches, gauges and indicator lights from 971 to 365. Computers control most of the 747-400's flight, including the landing. But they also help pilots monitor aircraft systems, enhancing safety by allowing flight crews to keep an eye on traffic.

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The Newest Way

With the most powerful jet engines ever built, the Boeing 777 is ready for takeoff.

BY DAWN STOVER

The 87-foot-high doors of the world's largest building opened on April 9, and out of a cavernous bay rolled the first Boeing 777. Scheduled to make its maiden flight this month, the 777 is the biggest twin-engine jetliner made, and it sports the most powerful jet engines ever built.

From the outside, the 777 looks similar to today's jetliners. Inside, passengers will notice a difference. The fuselage is more than 20 feet in diameter—only the giant 747 has a wider interior. And because the side walls are not as sharply contoured as those of other wide-body planes, passengers in the window seats will have more headroom. The customers who helped Boeing plan the 777—United Airlines, All Nippon Airways, Japan Airlines, and British Airways—insisted on spaciousness and other features that make the cabin more adaptable than in earlier models.

Built at a Boeing factory that covers more than 98 acres in Everett, Wash., the 777 incorporates the latest in computerized flight-control technology and high-efficiency fan-jet engines. The new airliner will carry 305 to 328 passengers in a three-class seating arrangement—filling the niche between the company's 218-passenger 767 model and the 420-passenger 747.

Large twinjets are popular with airlines because they use less fuel per passenger and require less maintenance than three- or four-engine aircraft do. But getting a plane the size of the 777 off the ground takes a lot of power. Three competing manufacturers have risen to the challenge and developed monster engines for the 777: the Pratt & Whitney PW4000, the General Electric GE90, and Rolls-Royce's Trent 800. So far, seven airlines have chosen the GE90 engine, while four airlines have each chosen one of the other two.

The new engines produce thrust of more than 80,000 pounds each. By comparison, the most powerful engines on the 747 produce about 60,000 pounds of thrust. All three of the 777 engine models are high-bypass turbofans that use a large, wide-bladed front fan to push massive quantities of air, only a small fraction of which passes through the powerplant's turbine core. These efficient engines are essentially turbine-driven ducted propellers. And they are big. The diameter of the GE90 engine's nacelle, for example, is about the same as the entire fuselage of a 757 airliner.

The 777 will be Boeing's first airliner using the "fly-by-wire" flight-control technology first adopted by the European Airbus consortium. The pilot's corrections are transmitted to the rudder, flaps, and other control surfaces electronically, rather than mechanically, after passing though a computer that generates the actual commands. The signals travel along simple twisted pairs of wires connected by vibration-tolerant inductive couplers that snap in place and interrogate the lines for the data flowing through them.

A feature called "fault tolerance" is built into the system. It was originally developed by the Air Force, which is interested in making combat-damaged fighters able to limp safely home. Should a 777 component such as a hydraulic flight-control actuator fail, the computer automatically reroutes its commands to an appropriate combination of control surfaces to keep the airliner stable and flyable. Three parallel fly-by-wire computer systems provide two

[Continued on page 104]

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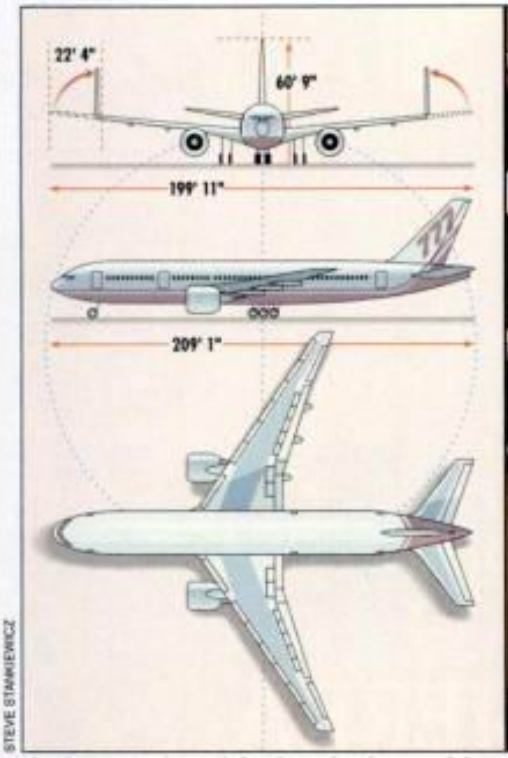
To Fly

TOUR OF THE 777

1. New 777 fanjet engines, built by three different manufacturers, are as quiet as those on the twinjet Boeing 767, but produce 40 percent more power.
2. Boeing offers optional folding wingtips that help the 777 squeeze into small airport departure gates, but no airlines have ordered this feature.
3. With a wider body than any jetliner except the Boeing 747, the 777 will provide three-class seating for 305 to 328 passengers, or two-class seating for 375 to 400 passengers.
4. Resistant to corrosion and fatigue, lightweight composite materials replace metals in the tail assembly and floor beams of the aircraft's passenger cabin.
5. The main landing gear has two six-wheel trucks, instead of conventional four-wheel units, for better weight distribution on runways.
6. "Flexibility zones" near the four doors allow airlines to move galleys and lavatories, reconfiguring the plane for different routes and seasons.



STEVE STANKIEWICZ

The drawings above (left) show the shape and dimensions of the 777. The flight deck (right) has a horizontal layout similar to that of the Boeing 747. Cathode-ray tubes have been replaced with lightweight liquid-crystal displays that save space and power and remain clearly visible in direct sunlight.

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nities—a technological behemoth exists that operates this 20th century engineering trophy.

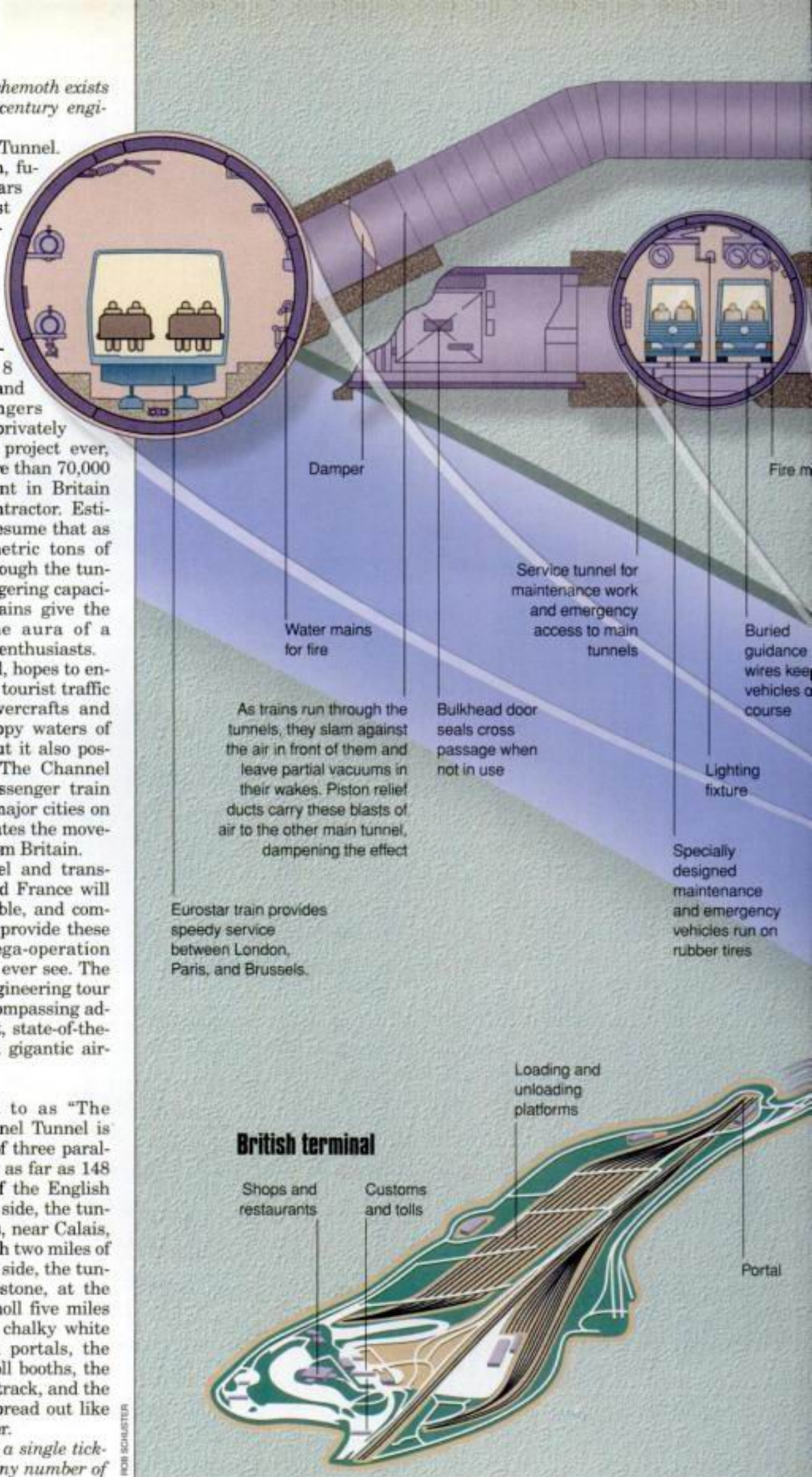
This is the Channel Tunnel. Dreamed of by Napoleon, futilely attempted 100 years ago, and built at a cost greater than most countries' gross national product, the 31-mile underwater rail link between England and continental Europe is finally in place. By 1996, the system will transport some 8 million car passengers and 4.5 million bus passengers each year. The largest privately financed infrastructure project ever, the Chunnel created more than 70,000 man-years of employment in Britain alone, estimates the contractor. Estimates from late 1992 presume that as much as 8.5 million metric tons of freight will also pass through the tunnels each year. This staggering capacity and the oversized trains give the system's terminals the aura of a "Jurassic Park" for train enthusiasts.

The owner, Eurotunnel, hopes to entice a large chunk of the tourist traffic that currently uses hovercrafts and ferries to cross the choppy waters of the English Channel. But it also possesses a larger vision: The Channel Tunnel opens direct passenger train service from London to major cities on the continent and facilitates the movement of freight to and from Britain.

Eurotunnel says travel and transport between Britain and France will now be simple, dependable, and competitively priced. But to provide these services requires a mega-operation that few passengers will ever see. The Channel Tunnel is an engineering tour de force, ingeniously encompassing advanced safety equipment, state-of-the-art control rooms and a gigantic air-conditioning system.

Commonly referred to as "The Chunnel," the Channel Tunnel is actually a complex of three parallel passageways, dipping as far as 148 feet below the seabed of the English Channel. On the French side, the tunnels surface at Coquelles, near Calais, after first passing beneath two miles of coastline. On the British side, the tunnel emerges near Folkestone, at the base of Castle Hill, a knoll five miles inland from the famous chalky white cliffs of Dover. At both portals, the loading platforms, the toll booths, the orderly stretches of new track, and the webs of catenary wire spread out like silt at the mouth of a river.

After James purchases a single ticket, good for his car and any number of

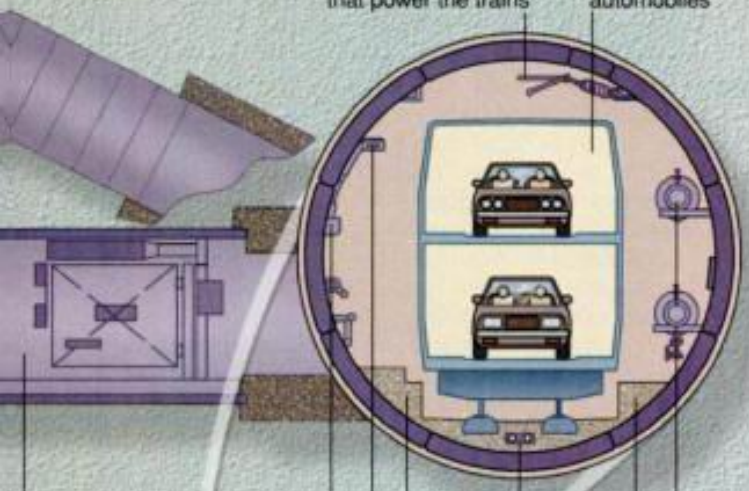


ROB SCHUSTER

INSIDE THE CHUNNEL

Essentially, the Channel Tunnel is a colossal, $13 billion rail shuttle system. Open 24 hours a day, 365 days a year, the system transfers automobiles, buses, trucks, people, and freight between England and the continent. More than an underground passageway, the Channel Tunnel includes sprawling terminals, specially designed rolling stock, air conditioning, drainage, lighting, safety, communication, and signalling systems.

The three parallel tubes—one for trains in each direction, plus a service corridor—are carved out of a layer of chalk marl beneath the sea floor of the English Channel. The shuttle trains race through the tunnels at speeds approaching 87 miles per hour.



Cross passage links main tunnels with service tunnel

Primary low-level lighting fixture illuminates the tunnel during normal operation.

Secondary lighting fixture for maintenance work and emergencies

Evacuation walkway

Drains collect water from rain and condensation, or liquids accidentally spilled

Walkway for maintenance work

Massive water pipes (outgoing and return) carry cooling water to counteract the heating effect of the running trains

Crossover areas enable trains to switch from one tunnel to another

Pumping stations collect water or spills from drainage pipes

French terminal

Shops and restaurants

Portal

Customs and tolls

Loading and unloading platforms

passengers, the Whitbys go through customs. Then James directs the car up a ramp and onto a loading bridge. Allison glances at her watch: 11:15 a.m. As the car idles while in line for the next shuttle train, the Whitbys command a good view of the terminal. To their left, a Brussels-bound passenger train slips into the gloom of the north tunnel entrance. Far ahead, a heavy fence conceals a cargo train churning down the Continental Main Line toward London.

With its brakes hissing, a silvery shuttle train slides up to the platform. The roadway barrier lifts, the light turns green, and, one by one, the cars roll down the loading ramp, onto the platform, and into the gaping hole in the shuttle's side. James dutifully maneuvers through three tubular train cars and comes to a halt behind a green Volvo. He switches off the ignition. A moment later a buzzer sounds, and clacking metal dividers descend from the ceiling at each end of the train car, sealing the Whitbys' Opel and four other vehicles onto one long, low-ceilinged rectangular compartment 12 feet wide, with gray ribbed floors and bare white walls.

The shuttle trains look inordinately large—and they are. At 13.5 feet across, Eurotunnel's shuttle cars are the widest train cars ever built. These rolling stock, each carrying ten vehicles, cost $3,200,000 apiece.

Each shuttle is a half-mile long: 12 double-decker cars for automobiles, 12 single-deck cars for buses, plus a pair of engines and the loading and unloading cars. Each electric locomotive is capable of hauling a 2,100-ton load at nearly 100 mph and has been fitted with a rarely used bogie arrangement: three sets of wheels, with twin, independently driven axles. This design improves the adhesion of the steel wheels to the track as the train negotiates sharp curves—important for the tight turnaround loops at each terminal.

Between shuttle trains, Eurotunnel schedules runs for Eurostar passenger trains, which provide nonstop, and, where rail quality allows, high-speed, rail trips between London and destinations on the continent. The locomotives used for these passenger trains are unique by any standard. Each must accommodate different electrical power pickup mechanisms, signalling systems, and voltages used by the British, French, and Belgian railways. To avoid the need to standardize three countries' entire rail systems, these trains can run on all three—not an easy task.

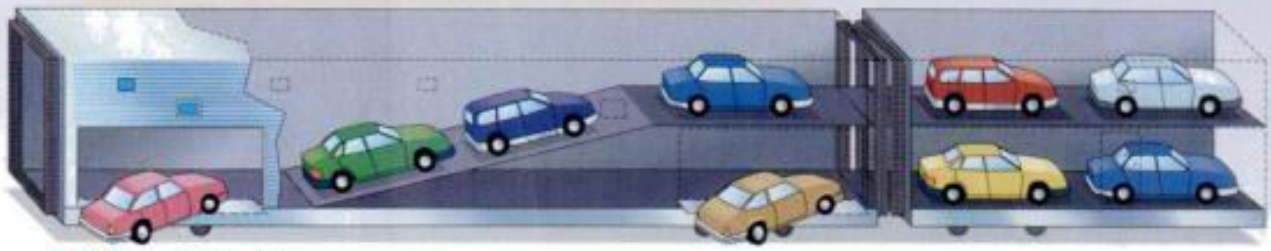
"To do that," explains Eurotunnel official Bill Coleman, "the Eurostar locomotives need three separate engines—one for each voltage. Also, the Channel Tunnel's intergovernmental commission specifies that all trains using the tunnel must be twin-engine," a safety precaution in the event of a breakdown. "That means," he continues, "each Eurostar locomotive has six engines. And that's not all—there is a locomotive at each end of the train. Altogether there are twelve engines on each Eurostar train."

With a gentle lurch, the train eases forward. Allison pulls several postcards out of her purse and begins to address them. James opens his car door and stands up, feeling the easy tremble of the moving train. To his right, a stairway leads to the upper level of the train car. To his left, sunlight pours through a small, square window; he walks over and peers out. Fences and a forest of catenary poles roll by. Then the glass goes black, and James realizes they've entered the tunnel.

Eleven massive tunneling machines—some as long as two football fields—bored the three tunnels that make up the Channel Tunnel complex. The gargantuan cutters gnawed perfectly round tubes through the semisoft cheese-like substrate of the English Channel, then used conveyors to expel the soggy spoil to the rear of the machines. Conveyor belt systems and

ALL ABOARD LE SHUTTLE

1 Le Shuttle train



2 How cars load

Eurotunnel expects to load a shuttle in approximately eight minutes. The state-of-the-art shuttle cars are equipped with an onboard computer to control functions like air conditioning and opening doors, a hydraulic stabilizing system, and a purging system to expel automobile fumes. Larger than most railroad cars, empty shuttle cars would be in danger of tipping over in high winds; tall wind fences were erected at the terminals to prevent such an event.

1 A typical Le Shuttle train includes 12 double-decker cars for automobiles, 12 cars for buses and campers, loading and unloading cars, plus a locomotive at each end. A full shuttle carries about 800 passengers. 2 Passenger cars simultaneously fill both the upper and lower decks via a ramp-equipped loading car. 3 Buses and campers enter the shuttle via a loading car with telescoping walls that seal shut when the train is in motion. Hydraulically powered plates bridge the gap between the pavement and the train. 4 Trucks are transported in lattice-walled cars; the drivers travel in a club car at one end of the shuttle.

4 How trucks

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other machinery helped remove the spoil to locations outside the tunnels. In all, the machines excavated roughly 245 million cubic feet of spoil to create the passages. Some of that was used to build an outcropping at the base of the famous white Shakespeare Cliff near Dover. On the French end, the spoil was mixed with water, then this slurry was pumped out and dumped behind a 132-foot-tall dike. This mountainous, soggy heap should finally solidify in 1995; it will then be landscaped and used as a park.

The tunnels themselves are exceptionally sturdy. They are lined with arch-shaped, five-foot-thick concrete segments. To make the concrete extremely strong, granite aggregate mined from the heart of a Scottish mountain was used.

For the most part, the three tunnels lie parallel. But twice along their 31-mile paths, the service tunnel veers deeper and northward, and the two traffic-bearing tunnels converge in a cavernous crossover—515 feet long, 60 feet wide, and approximately 30 feet high. Separated by huge, 99-foot-long sliding steel doors, the crossover stations enable trains to switch from one tunnel to the other.

That, however, is not standard practice. Except in emergencies or during tunnel maintenance, trains run

TACKLING THE TERRORIST THREAT

From a terrorist's point of view, the Channel Tunnel presents an enticing target: It will handle large numbers of travelers, operate around the clock, and, above all, stand as a symbol of the growing cohesion of European nations.

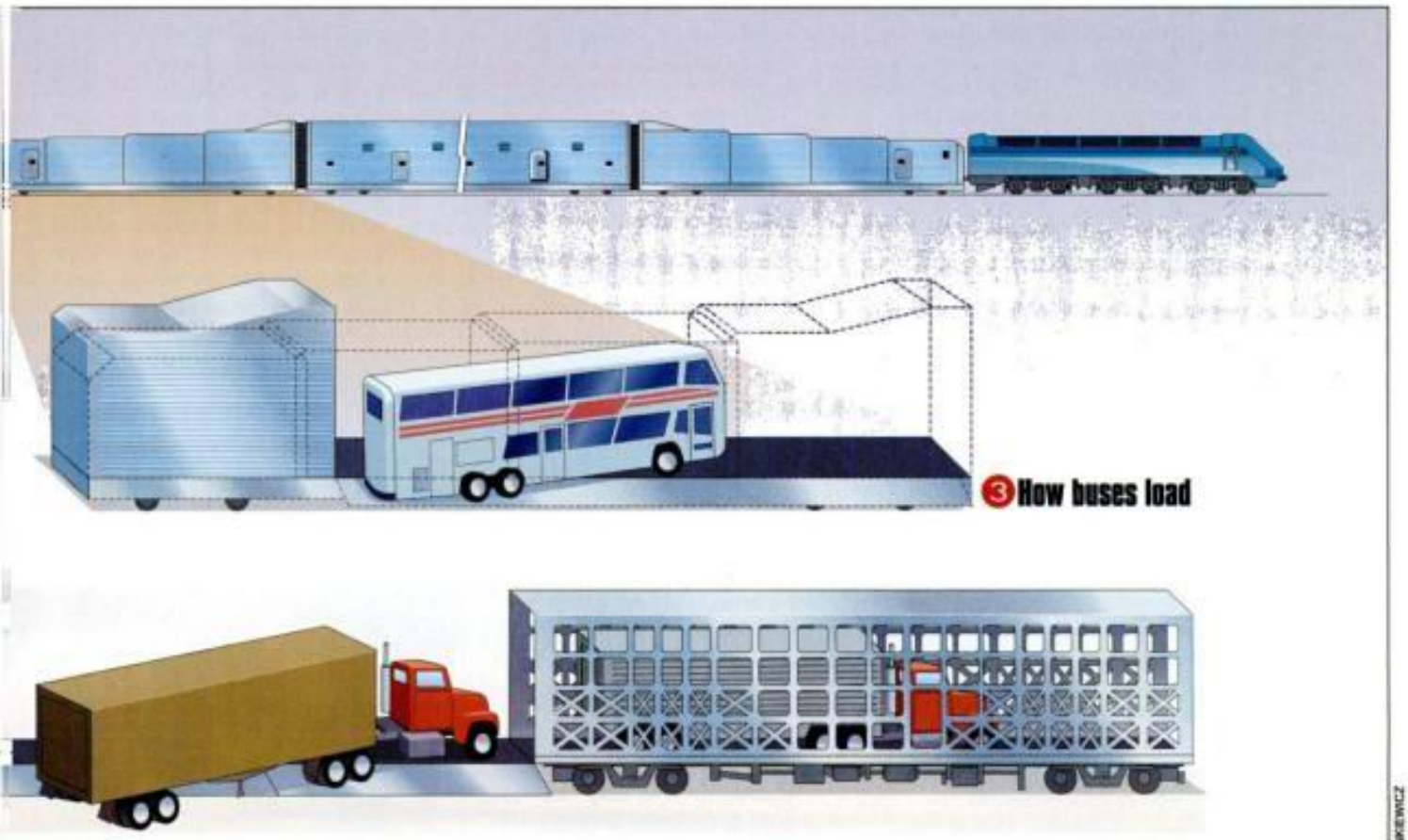
"Terrorism is an area where we've had to be scrupulously careful from the word 'go,'" remarks Eurotunnel's John Noulton. "Our philosophy has been to make this as tough a nut to crack as possible."

There are two types of shuttle trains—one for cars and buses, the other for trucks—and the Channel Tunnel security must prevent a bomb-laden vehicle from slipping aboard either type. The car-and-bus shuttles, says Noulton, are less of a concern, because passengers must stay with their vehicles during the entire trip. That arrangement should discourage anyone from setting off an incendiary device—unless the terrorist is suicidal.

One looming threat, explains Noulton, is a bomb on a truck shuttle, because truck drivers park their rigs on an open-air shuttle and then ride in a separate club car. Theoretically, a terrorist could place a bomb-laden truck aboard the shuttle and sneak off before the train leaves the station.

To counter that threat, Eurotunnel installed "the most sophisticated scanning device for trucks in the world," says Noulton. Called Euroscan, the system looks for bombs and other contraband, including drugs. While Noulton declined to elaborate, the system probably includes a bomb "sniffer," an electronic device that can detect telltale traces of explosive molecules in parts per billion. Euroscan likely also uses some form of radiation to search for the organic compounds that constitute most bombs. Both terminals are equipped with the Euroscan system, housed in flat-roofed beige structures set far back from the bustle of the toll booths and rest-stop buildings. The idea is to catch terrorists before they reach the loading platforms.

It is also possible, says one Eurotunnel source, that "private vehicles will be scanned without the passengers knowing it." The covert screening—again, possibly performed by sniffers—could take place at one of the several stops before shuttle boarding, such as at a toll booth or customs checkpoint. According to the source, the plan is being discussed by the intergovernmental commission that oversees the Channel Tunnel system. —*J. G.*



3 How buses load

STEVE STANKIEWICZ

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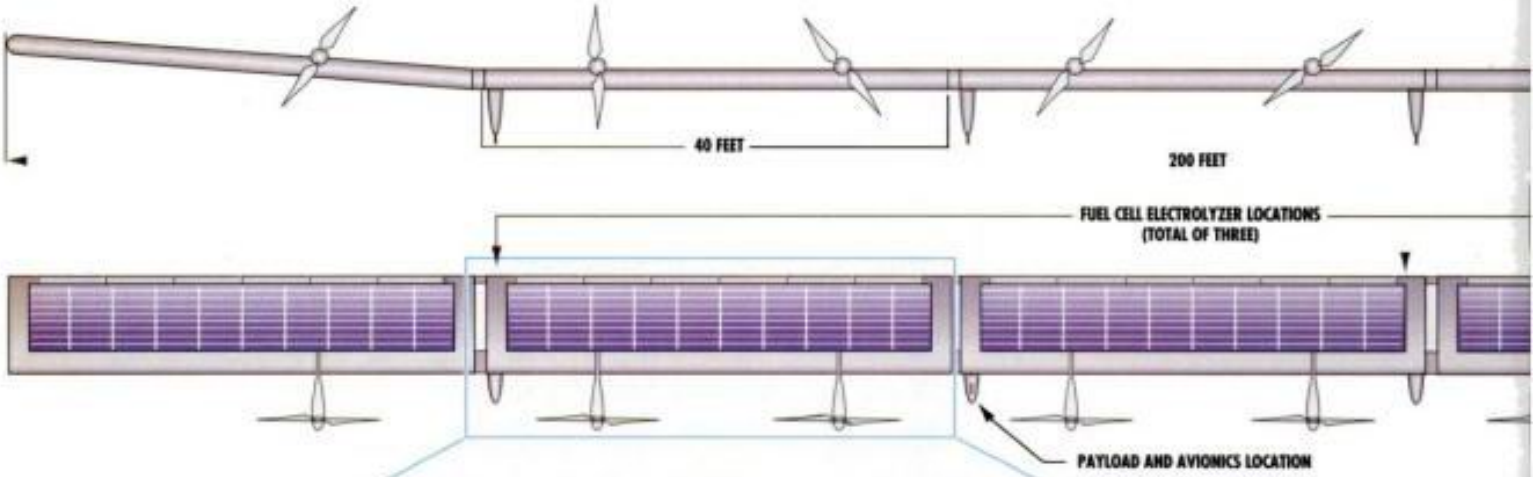
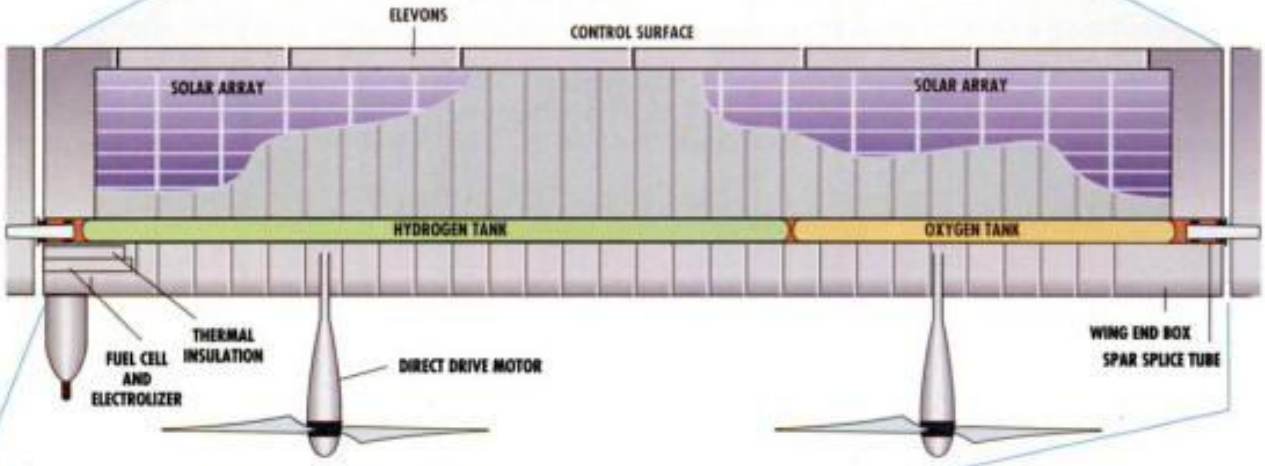
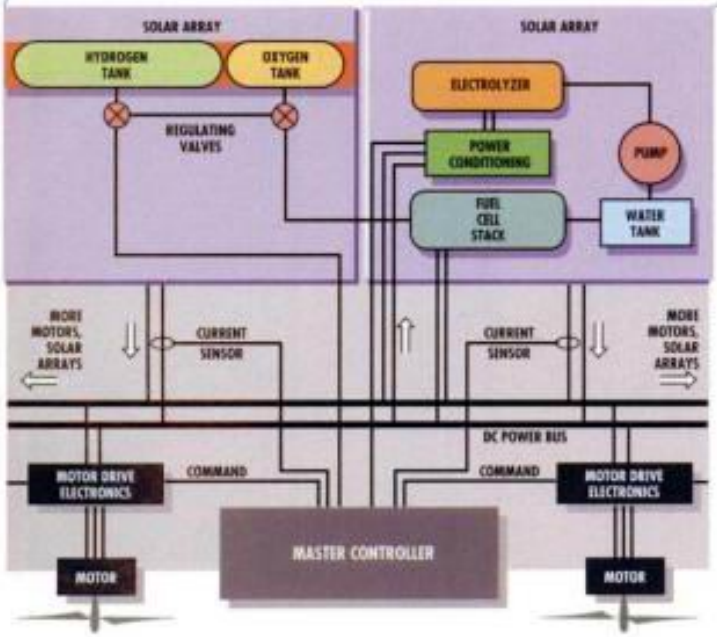
200-FOOT HELIOS: THE NEXT SOLAR ELECTRIC WING







The planned successor to the Pathfinder is called Helios. Its 200-foot span (top) is comprised of five modular, 40-foot sections, supported by a quartet of landing pods. Eight electric motor-propeller units similar to Pathfinder's provide propulsion. A tubular carbon- and aramid-fiber wing spar running across the span is the main structural element. Proton-exchange membrane fuel cells located above three of the landing pods serve as storage batteries. During sunlight hours, surplus current from the solar array electrolyzes water into hydrogen and oxygen gases, which are compressed and stored inside the wing spar. At night, the fuel cells provide electricity for the engines by recombining the gases. The sole by-product—water—is stored, and the closed-loop cycle repeats daily (see diagram at left). The Helios will carry its avionics system and 150-pound payload above one of the inboard landing pods.

several types of chemical batteries, and hydrogen-oxygen regenerative fuel cells were compared.

The fuel cells are clear winners, according to Dr. Nicholas Colella, program manager at Livermore. They have an energy density of 300 watt-hours per kilogram, which is about ten times that of lead-acid batteries and more than twice the energy density of advanced zinc-air batteries.

"We found out that the essence of the fuel cell, which in our case is a proton-exchange membrane electrolyzer, exists and is used in underwater vehicles, so we don't have to invent it," Colella says. "The same membrane performs both the electrolysis and the combining of the gases to make water. We

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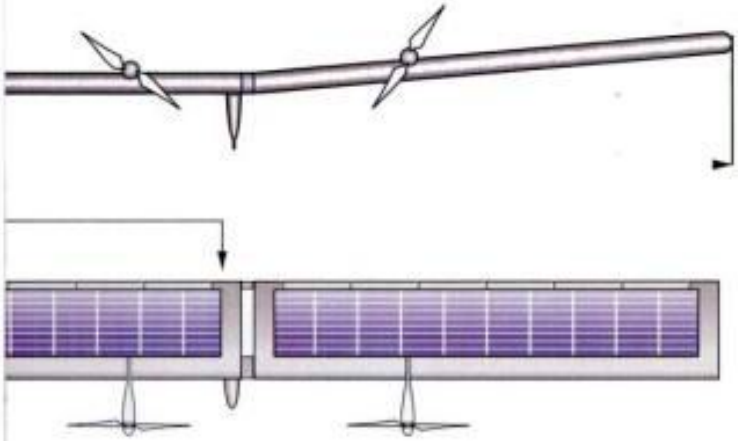
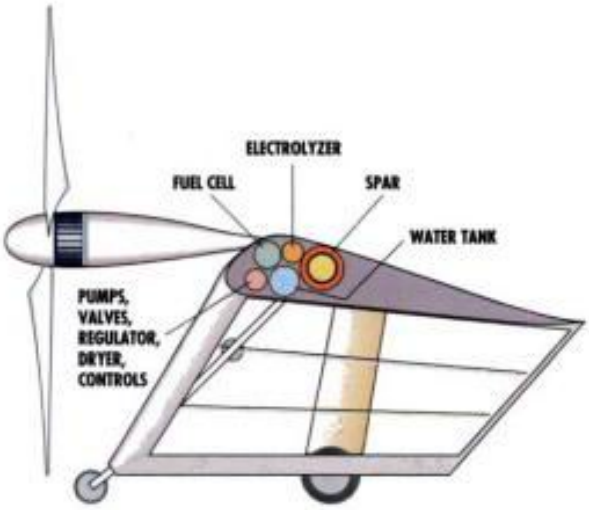




need to package it into a lightweight system, which will take about two years of engineering. But no fundamental breakthrough is needed in the chemistry or the materials."

The airframe now called Pathfinder has a mysterious past. It first flew in 1983 under the name HALSOL (high-altitude solar energy) as part of a classified program sponsored by an unnamed agency to explore the feasibility of long-duration, solar-electric flight in the calm air at altitudes above 65,000 feet. HALSOL flew nine times in two months, eventually reaching an altitude of 2,000 feet powered by rechargeable silver-zinc batteries.

Sources outside the program have revealed that testing took place at the unacknowledged air base at Groom Lake, Nevada. Organizations known to have studied sun-powered aircraft include the Air Force, the Naval Research Laboratory, the Central Intelligence Agency, the National Reconnaissance Office, and NASA. Which one was the customer? That's a secret.

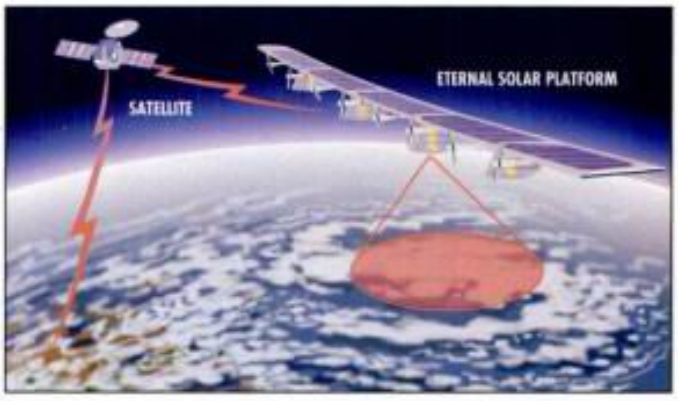
The craft proved airworthy but would clearly have become too heavy to carry a useful payload if equipped with the solar arrays and power-control equipment then available. HALSOL embodied ideas that were ahead of the state of technology in 1980, and it was parked in long-term storage.

The rebirth of HALSOL as the Pathfinder is a dramatic confirmation of the rapid leaps in miniaturization and performance presently taking place in the electronics world. The airplane that couldn't achieve pure solar-powered

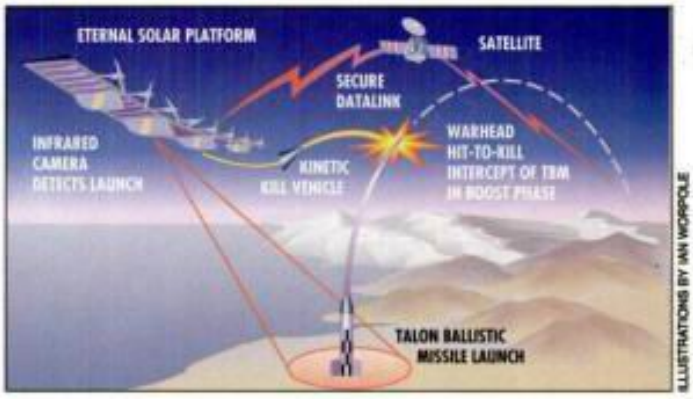
[Continued on page 100]

JOBS FOR LONG-DURATION HIGH FLYERS

An eternal airplane could function as an atmospheric "pseudo-satellite" providing a relocatable, over-the-horizon communications relay, or a persistent platform for reconnaissance sensors. In military use, the craft would fly a racetrack-shaped pattern above friendly territory and peer into areas of conflict. Civil roles might include border patrol and disaster management during forest fires or earthquakes, when local telecommunications are interrupted.



Severe-storm tracking at altitudes of 60,000 to 80,000 feet is a likely role for an eternal airplane. Flying above a hurricane's fury, the drone could monitor the storm's evolution and course, warning of an impending landfall. Because it is electrically powered and breathes no air, the plane could safely fly atmospheric-sampling missions through abrasive volcanic ash or the radiation released in a nuclear powerplant accident.



ILLUSTRATIONS BY IAN WORPOLE

The Ballistic Missile Defense Organization is exploring solar drones as platforms for detecting launches of Scud-type ballistic missiles, then attacking them during the boost phase of their flight, when the missile's exhaust plume is easily detectable by infrared sensors. A 50-pound kinetic-kill rocket called Talon would be launched from the drone's landing pod, destroying the missile in a mid-course collision.

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Finger Signs

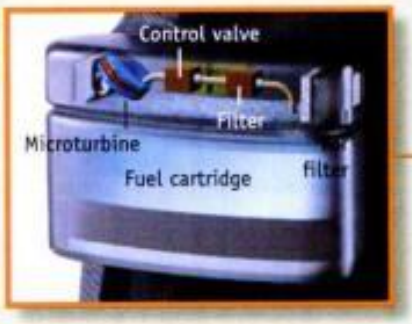
Sensors in the glove track hand and finger movements that microprocessors translate into digital signals that can be relayed via radio.

Water Supply

The traditional hip-mounted canteen gives way to a water sack similar to those used by skiers and cyclists. Water is drawn from a tube inside the helmet.

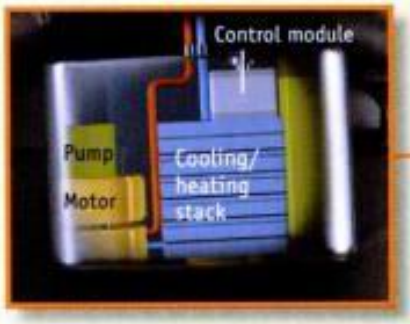
Body Armor

The outer layer consists of ballistic-resistant ceramics backed by a composite material made with carbon nanotubes that are as strong as steel. Extra ammo is stored here.



Power System

Microturbines fueled by liquid hydrogen would provide a steady 2 watts of power that can surge to 20 watts if needed. Ten ounces of fuel contained in lightweight, plug-in cartridges would last six days.



Air Conditioning

A low-power, climate-conditioning system worn on the hip would cool or warm the soldier as needed. The 5-pound device would use a microturbine for power with batteries as backup.

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THE SECRET SHIP

An experiment in seagoing stealth glides out of the black.

BY STUART F. BROWN

Sea Shadow has a top speed of 13 knots; the four-man crew enters through a hatch on the starboard side.

Think of a trilobite navigating the primordial ooze. Think of pyramids, cut gemstones, or the ironclad ship *Merrimac* that fought for the Confederacy in the American Civil War. And, of course, think of the F-117A stealth attack plane. The mysterious form that emerged from the military's secret world earlier this year brings all of these shapes to mind.

As the doors of a huge floating dry dock slid open in the waters off California's Santa Cruz Island, a black, faceted shape began to move into the open sea amid wisps of bluish exhaust smoke. Onlookers aboard a Coast Guard cutter noticed light-colored, submerged shapes beneath its steeply sloped edges. By the time the entire 160-foot craft was free of the structure, a row of windows could be seen in one of its pointy, four-surfaced ends. It was running in reverse.

This was the first public glimpse of *Sea Shadow*, a U.S. Navy test vessel unlike anything seen before. Its existence had been carefully concealed since 1986, when the Navy concluded a series of covert and costly nighttime sea trials. The need for a round of daylight testing, the Navy says, led to the decision to unveil the ship. There wasn't much choice; aircraft or offshore boaters would soon have spotted it.

If airplanes can be made difficult to detect by radar and other sensors, why not try applying stealth technology to a ship? The Navy began thinking this way in the late 1970s, when the ultra-secret Have Blue, a prototype for the Air Force F-117A, was proving elusive to radar during flight testing at the secure Groom Lake base in Nevada.

The Navy says *Sea Shadow* isn't the first of a new class of ship, but rather was built to test several aspects of maintaining stealthiness at sea, including low radar visibility, quietness to sonar sensors, and minimizing wake.

Sea Shadow's resemblance to the Black Jet used successfully in the Persian Gulf war is no coincidence. The two shapes are products of Lockheed Corp.'s Advanced Development Projects organization, also known as the Skunk Works. The Skunk Works applied its expertise in reducing radar signatures, then passed the project to the company's Missiles and Space division, which engineered and quietly constructed the craft inside the Hughes Mining Barge moored at Redwood City in the San Francisco Bay area.

Ballast tanks aboard the seagoing barge can be flooded, lowering the interior floor level until the stealth ship is afloat on its twin pontoons. The barge itself has an exotic history. It was used 20 years ago to conceal Lockheed's fabrication of a giant claw used by the ship *Glomar Explorer* in a CIA-funded project to retrieve a Soviet submarine sunk in waters 17,000 feet deep off Hawaii.

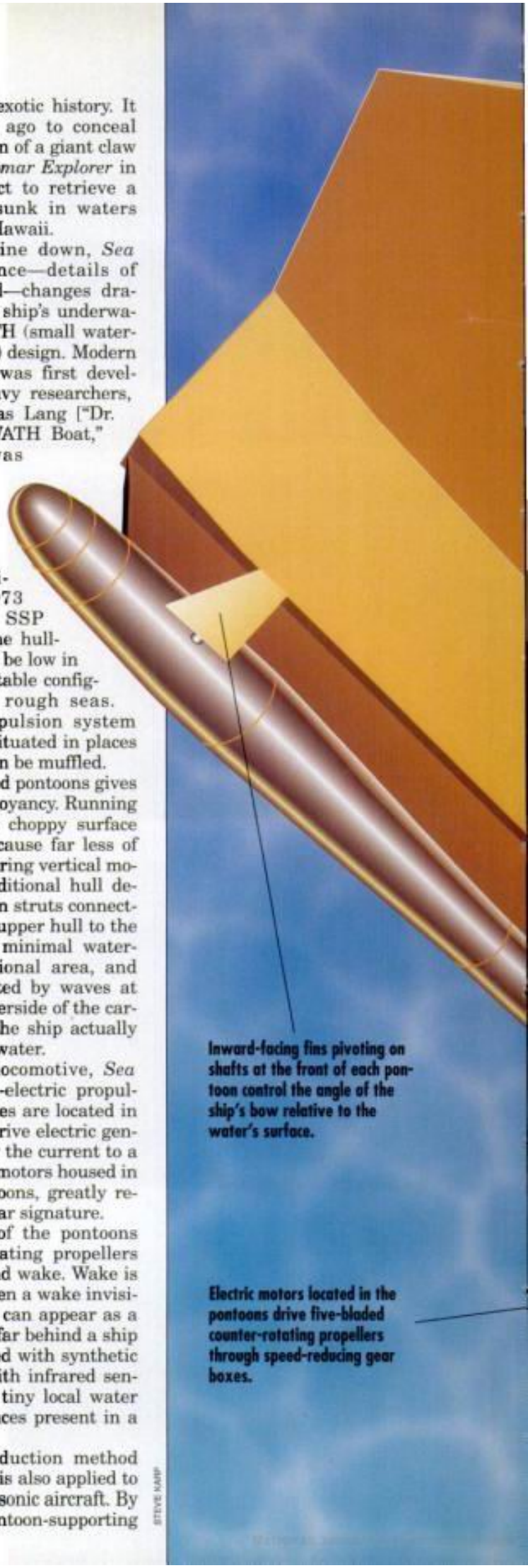
From the waterline down, *Sea Shadow's* appearance—details of which are classified—changes dramatically. The black ship's underwater shape is a SWATH (small waterplane-area twin hull) design. Modern SWATH technology was first developed in 1970 by Navy researchers, including Dr. Thomas Lang ["Dr. Lang's Amazing SWATH Boat," April '91], who was then head of the advanced concepts group at the Naval Ocean Systems Center in San Diego. The Navy's experience with its 1973 SWATH test ship SSP *Kaimalino* proved the hull-shaping technique to be low in drag and the most stable configuration known in rough seas. Further, noisy propulsion system components can be situated in places where their sound can be muffled.

A pair of submerged pontoons gives a SWATH ship its buoyancy. Running beneath the water's choppy surface layer, the pontoons cause far less of the seasickness-inspiring vertical motion inherent in traditional hull designs. The pair of thin struts connecting a SWATH ship's upper hull to the pontoons also have minimal waterplane, or cross-sectional area, and thus are little affected by waves at the surface. The underside of the cargo-carrying part of the ship actually rides well above the water.

Like a railroad locomotive, *Sea Shadow* uses diesel-electric propulsion. Its diesel engines are located in the upper hull and drive electric generators. Cables carry the current to a pair of quiet electric motors housed in the submerged pontoons, greatly reducing the ship's sonar signature.

Careful shaping of the pontoons and the counter-rotating propellers helps reduce drag and wake. Wake is a serious concern; even a wake invisible to the naked eye can appear as a bright trace trailing far behind a ship to a satellite equipped with synthetic aperture radar or with infrared sensors looking for the tiny local water temperature differences present in a churning wake.

One key wake-reduction method used in *Sea Shadow* is also applied to cutting drag in supersonic aircraft. By giving the ship's pontoon-supporting

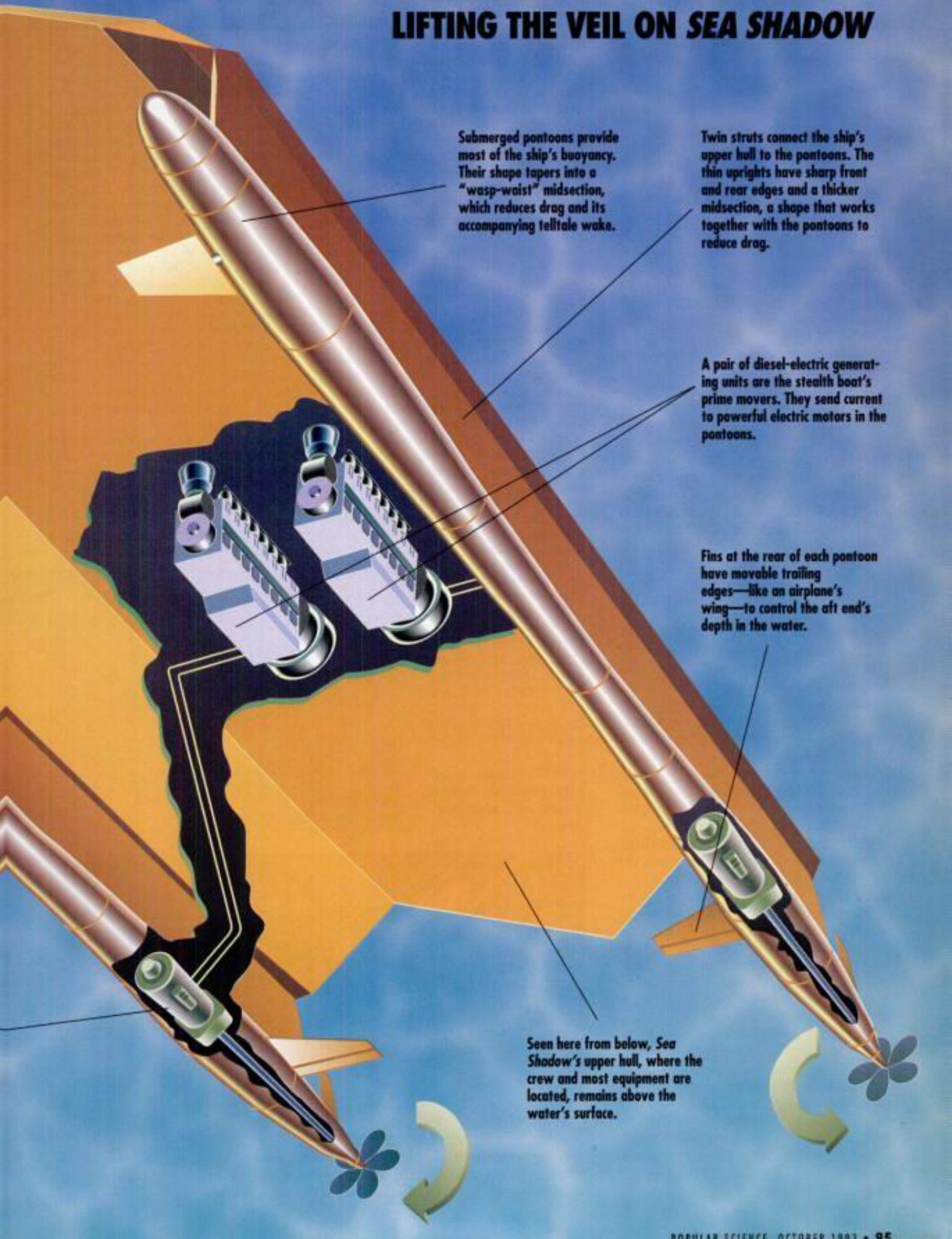


Inward-facing fins pivoting on shafts at the front of each pontoon control the angle of the ship's bow relative to the water's surface.

Electric motors located in the pontoons drive five-bladed counter-rotating propellers through speed-reducing gear boxes.

STEVE KARP

LIFTING THE VEIL ON *SEA SHADOW*



helmet, the squad leader is reminiscent of the Power Ranger toy figurine the enemy soldier played with as a child. Even as he watches, the squad leader's uniform is changing color, blending into the background like a chameleon—or an alien.

These are among the enemy soldier's last thoughts. Some 1,000 meters away, another squad member has seized the high ground atop the roof of a taller building. The enemy is plainly visible thanks to the zoom camera image on a visor display. At this range, the enemy is too far away for standard rounds to be effective. The squad member extends his arm, hand angled slightly downward, and whispers, "Fire on target." With a small whoosh, one of four 15-millimeter projectiles streaks from the munition pod strapped to his wrist.

Suddenly, the enemy is on the move, squeezing off a few rounds of covering fire as he runs. The projectile is already compensating. Tiny heat-seeking sensors have acquired the target, and the projectile alters course. The chase is a short one. The projectile explodes like a hand grenade, spreading shrapnel 30 meters in every direction. Even a last-second dodge would have been useless.

Death seeks a companion. A round fired by the enemy soldier has hit the squad leader. "Man down" sounds like a refrain through the squad, echoing up the chain of command. It's quickly apparent the squad leader is only slightly stunned, thanks to an outer layer of body armor. While not totally bulletproof, the body armor can stop a small-caliber round.

Medics at headquarters quickly confirm the initial diagnosis. The inside layer of the uniform contains a network of microsensors in contact with the skin. Life-support data is automatically transmitted to headquarters every few seconds. The medics can see that the squad leader's heart rate and stress level are up, but otherwise he's fine. He has worked up quite a sweat, though, so the portable air conditioner on his belt promptly starts circulating coolant via tiny tubes that run throughout his uniform.

"You're fine. Have a drink of water." The squad leader hears the message through a receiver inside his helmet that conducts sounds through the bones of his head—no one but he can hear the voice, so communications won't give away his position. The squad leader sucks from a tube inside his helmet that connects to a water pack hanging from his back. He remembers using a commercial version of the product while skiing on his last leave, and the memory is somehow calming. He makes the OK sign with his fingers. The fingertips of his glove contain sensors, and the microprocessors embedded in his helmet recognize the pattern, transmitting the image to the other squad members and to headquarters, where the medics smile in relief.

For now, the scenario described above is only a dream in the mind of Sgt. Joe Patterson. But according to Patterson and other military planners, this type of firefight will take place in the real world 25 years from now.

Today, though, Patterson is already dressed in the form-fitting black uniform, the black motorcycle helmet in his hand. He is a walking blueprint of the U.S. Army's vision of what soldiers will look like in 2025. None of his equipment works—yet.

Patterson, a 6-foot-tall, 200-pound veteran of the 82nd Airborne Division, is the liaison between the infantry and the eggheads at the U.S. Army's Soldier Systems Center in Natick, Massachusetts. Together, they're developing technology guidelines for private industry and academia. Patterson's job is to stroll into labs around the country and explain what the soldier of the future will need. The message is simple: "Here is where we want to be. Help us get there," says Tom Tassinari, a senior physical scientist at Natick.

Natick's Future Warrior 2025 concept is a collection of subsystems covering everything from weapons to communications to medical care. Scientists working in the lab's Building 41, as it is commonly known, break

BATTLE GEAR, 2025

SENDING SOLDIERS into harm's way will entail highly advanced equipment if the army's view of the soldier of the future comes true. Much of it still needs to be developed.

Helmet

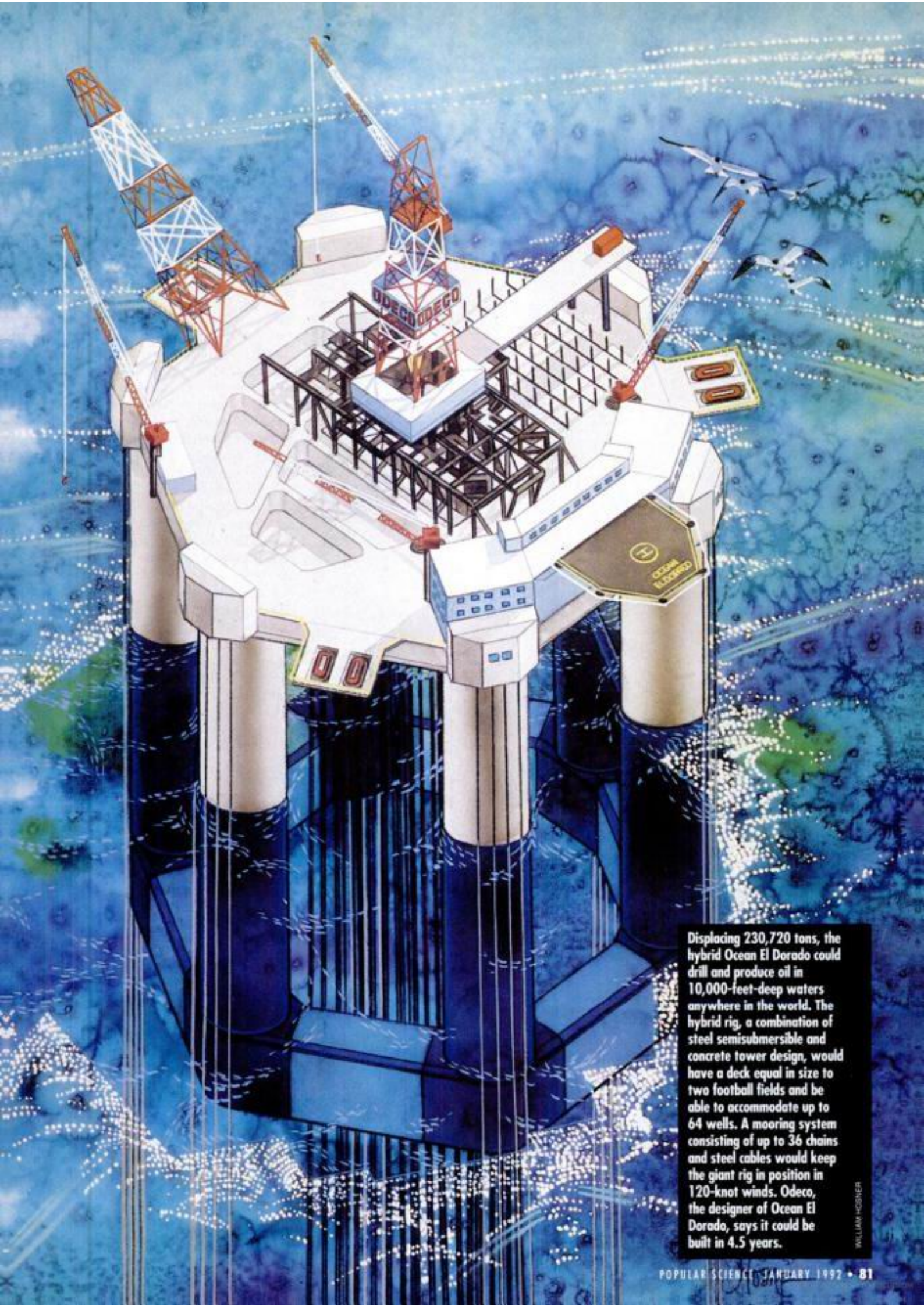
Microprocessors would warp images to match the curvature of the visor for a 180-degree view, while eight helmet-mounted sensors provide 360-degree situational awareness.

Battle Dress

The outer layer includes catalysts that can induce a change in color. The middle layer is a power conduit, and the inner layer monitors life signs.

Weapons Pod

The 5-pound weapons pod mounted on the soldier's forearm uses a clip of 4.6mm bullets as well as 15mm guided mini-rockets launched by microelectromechanical thrusters.



Displacing 230,720 tons, the hybrid Ocean El Dorado could drill and produce oil in 10,000-feet-deep waters anywhere in the world. The hybrid rig, a combination of steel semisubmersible and concrete tower design, would have a deck equal in size to two football fields and be able to accommodate up to 64 wells. A mooring system consisting of up to 36 chains and steel cables would keep the giant rig in position in 120-knot winds. Odeco, the designer of Ocean El Dorado, says it could be built in 4.5 years.

WILLIAM HOSHER

Repairing damaged blood cells
Removing blockage
Delivering drugs
Attacking viruses
Repairing cell walls

Incredible Shrinking Doctors

Microscopic machines may someday take a voyage through our bodies to repair damage, treat tumors, and more.

By Dan Cray

WITH A CLINK of retracting lock pins and the ensuing creak of an opening door, Ari Requicha withdraws his key and declares mischievously, "Time to shoot a little pool."

Requicha, a professor of computer science, isn't exactly a shark—but then again, this isn't going to be a routine game of pool. The field of play is situated on a dime-sized disk of mica loaded into a scanning electron microscope on the University of Southern California campus. A nearby computer screen displays a 1-square-micron segment of the mica slug's surface. The image is in black and white, but a smattering of polyoidic gold balls that measure about 5 nanometers in diameter—one-five-hundredth the size of a red blood cell—stand out as bright dots on the screen. Requicha takes hold of the mouse, draws a red arrow that intersects the heart of one of the balls, and clicks Enter. In a fraction of a second, a set of tiny cantilevers lowers a metallic tip that makes contact with one of the balls, which darts to the edge of the screen—a nice shot to the corner pocket.

Such expert manipulation of micro-matter is happening in labs throughout the country, representing the baby steps of a technology that could eventually produce molecular-sized robots capable of repairing living cells as they navigate the human body's internal passageways.

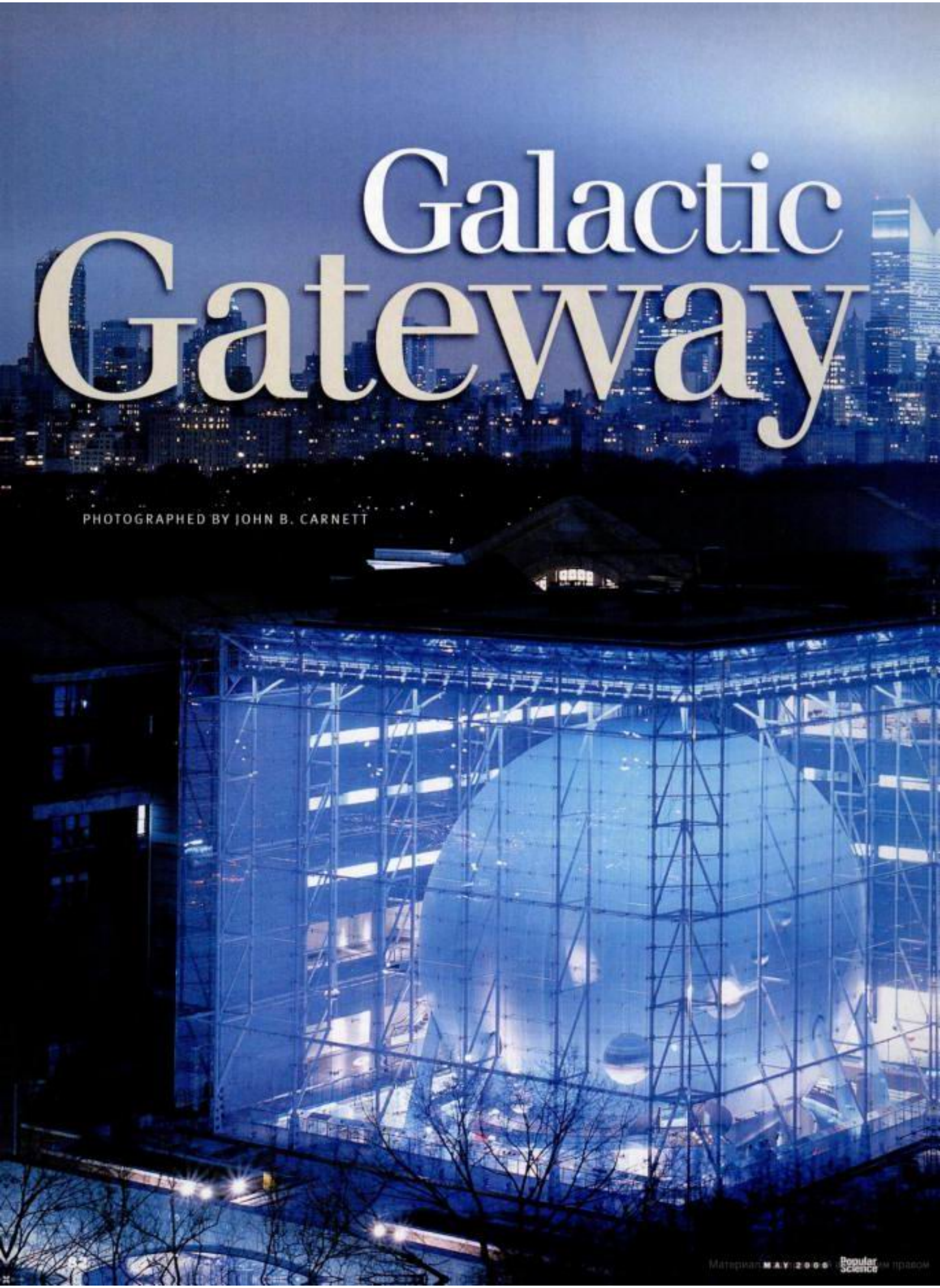
"We're no longer restricted to what nature builds, and that has incredible health care implications," says Requicha. According to prophets of nanorobotics, the so-called nanobots will be mass-produced in such miniscule size—far less than the diameter of a human hair—that they will be able to travel through capillaries without being rejected by the body's immune system, enabling them to seek out and eradicate diseased cells, then build healthy cells exactly where the body needs them.

If it sounds familiar, it should. From cinema's *Fantastic Voyage* to the works of Isaac Asimov, science fiction has long embraced the concept of nanomachines capable of repairing humanity's ills. In 1992, the

Scientists are laying the groundwork today for microscopic medics that will travel through the body, making repairs or treating ailments.

Galactic Gateway

PHOTOGRAPHED BY JOHN B. CARNETT



High-tech computers and projectors make the new Hayden Planetarium our best portal to explore Earth's place in the universe.

By Bob Sillery

WHAT'S THE difference between flying a spacecraft through the Milky Way and pretending to do so? Plenty—until now, that is. New technology at the recently reopened Hayden Planetarium in New York City is putting the reality in virtual reality like never before. To wit: "When we sweep past the rings of Saturn," says Neil de Grasse Tyson, the planetarium's director, "I duck."

So do I. Every time.

Looking august and otherworldly—shown at left bathed in blue light at midnight—the 4-million-pound, 87-foot-diameter plane-

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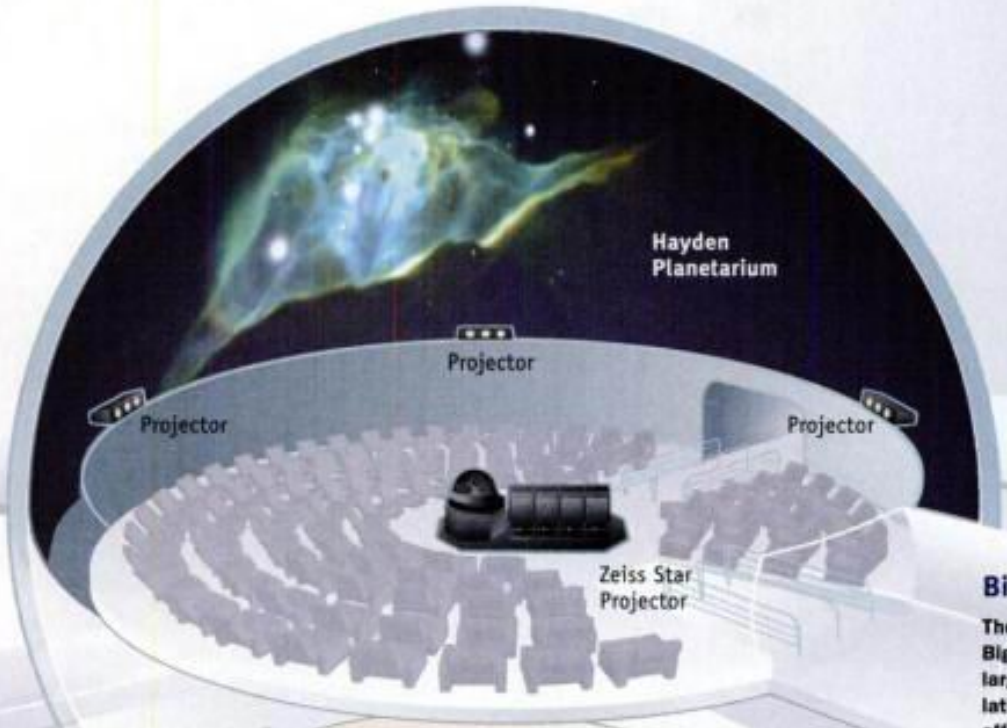
Unveiling the Rose Center

THE ROSE CENTER for Earth and Space at the American Museum of Natural History comprises the Hall of the Universe—with its crown jewel, the new spherical Hayden Planetarium—and the Hall of Planet Earth (not shown), which opened in 1999.



Hayden Planetarium

At the planetarium's Space Theater, scientists and artists have modeled the latest astronomical data into a 3-D, high-definition 20-minute trip through the universe that's projected onto the planetarium's dome. The Zeiss Star Projector (below) captures the majesty of the night sky. Then, controlled by a Silicon Graphics supercomputer, seven high-power projectors simulate flight through the stars.

Big Bang Theater

The bottom half of the sphere houses the Big Bang Theater. Visitors look down into a large bowl on the inverted dome for a simulation of the birth of the universe. Rumbling effects accompany rushing, swirling sensations as pent-up forces explode.

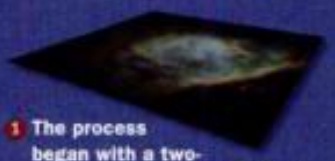
Cosmic Pathway

This 350-foot ramp, with 220 images, represents 13 billion years of cosmic evolution. The period of human history is the width of a strand of hair.

Scales of the Universe

This walkway uses the size of the Hayden sphere itself as a reference to create proportions for everything from the size of the universe to that of the atom. This immersive 3-D learning typifies the entire Rose Center.

Rendering the Orion Nebula To reproduce the nebula's data-intensive luminescence, whispy gas and dust, and other components in *Passport to the Universe,* the museum teamed with the San Diego Supercomputer Center.



1 The process began with a two-dimensional image taken by the Hubble Space Telescope. Because of the reddening and obscuring effects of interplanetary dust, the image was digitally corrected.

2 Based on previous research, scientists were able to infer the topography of the nebula, giving it height and depth. About 90 sublayers were then added to the rendering.

3 Using 3-D models of each component, researchers added a third dimension (above). Then working with 3-D pixels, or voxels, a supercomputer generated 28,000 high-resolution images for the fly-through (right).

COURTESY OF CARTER EMMART; AMNH (2)

INFOGRAPHIC MIKA GRONDAHL

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Finger Signs

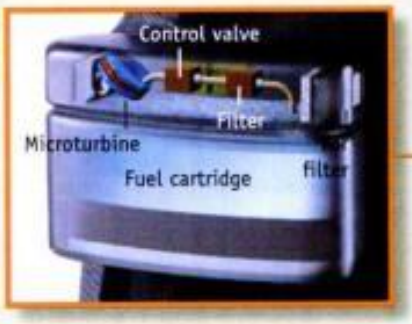
Sensors in the glove track hand and finger movements that microprocessors translate into digital signals that can be relayed via radio.

Water Supply

The traditional hip-mounted canteen gives way to a water sack similar to those used by skiers and cyclists. Water is drawn from a tube inside the helmet.

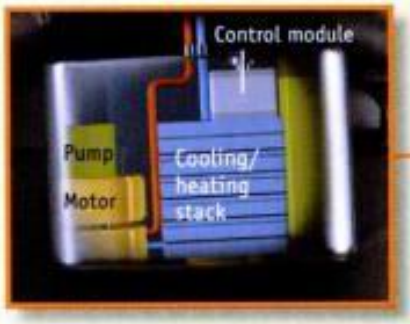
Body Armor

The outer layer consists of ballistic-resistant ceramics backed by a composite material made with carbon nanotubes that are as strong as steel. Extra ammo is stored here.



Power System

Microturbines fueled by liquid hydrogen would provide a steady 2 watts of power that can surge to 20 watts if needed. Ten ounces of fuel contained in lightweight, plug-in cartridges would last six days.



Air Conditioning

A low-power, climate-conditioning system worn on the hip would cool or warm the soldier as needed. The 5-pound device would use a microturbine for power with batteries as backup.

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